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A COMPARISON OF SYMPTOMATOLOGY AND PERFORMANCE DEGRADATION FOR MOTION AND RADIATION SICKNESS

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This report quantifies for the first time the relationship between the signs and symptoms of acute radiation sickness and those of motion sickness. With this relationship, a quantitative comparison is made between data on human performance degradation during motion sickness and estimates of performance degradation during radiation sickness. The comparison validates estimates made by the Intermediate Dose Program on the performance degradation from acute radiation sickness.

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SUMMARY

This report quantifies for the first time the relationship between the signs and symptoms of acute radiation sickness and those of motion sickness. With this relationship, a quantitative comparison is made between data on human performance degradation during motion sickness and estimates of performance degradation during radiation sickness.

For motion sickness, this report uses information and data compiled for a U.S. Coast Guard and Navy study [Wiker, Pepper, and McCauley, 1980] which measured human performance degradation caused by seasickness. Results from that study are compared with estimates obtained by the Defense Nuclear Agency's Intermediate Dose Program [Anno, Wilson, and Dore, 1983] on the performance degradation for Army combat crew tasks during acute radiation sickness.

Comparisons were feasible because of similarities in the symptom severity scales developed independently for the two sicknesses. Although the tasks treated in the two studies were not identical, parallels were sufficient to allow some general conclusions on the performance degradations for equivalent symptoms.

First, the motion sickness data corroborates the judgment of Army operational personnel on the relative performance degradation caused by different symptom combinations. Second, for equivalent symptoms, the Army estimates of performance decrements from radiation sickness are quite similar in magnitude to the measured performance decrements of Coast Guardsmen during seasickness. Finally, the Army performance estimates were significantly better correlated with performance measurements on Coast Guard tasks having task completion times similar to the Army tasks than with Coast Guard tasks requiring substantially longer completion times.

Being based on human performance data, these comparisons provide the strongest support to date for the validity of the estimates made by the Intermediate Dose Program on the performance degradation from acute radiation sickness.

PREFACE

This note reports on material provided for the Defense Nuclear Agency (DNA) Intermediate Dose Program (IDP) to assess the effects of nuclear weapon radiation on military troop performance. It represents one of a series of volumes comprising the DNA IDP report.

This note makes quantitative comparisons between the IDP performance estimates for combat troops suffering from radiation sickness and empirical performance data for Coast Guardsmen suffering from motion sickness. Along with the IDP Core Group, DNA staff members David L. Auton and Robert W. Young of Science and Technology, Biomedical Effects (STBE) guided this effort. The authors acknowledge the valuable assistance provided by G. Anno, M. Dore, and G. Hall who provided the IDP data in the required format. Special recognition goes to S. Levin and R. Young without whose encouragement and initial investigations this work would not have been done.

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INTRODUCTION

This report quantifies the correspondence between the signs and symptoms of motion sickness and those of acute radiation sickness and then examines the extent to which motion sickness data validate recent estimates of performance decrement for radiation sickness.

Only very limited data are available on human performance capability during illness caused by exposure to ionizing radiation. The Defense Nuclear Agency (DNA) has conducted a program to estimate the performance degradation on certain U.S. Army combat tasks due to acute radiation sickness based solely on the expert judgment of U.S. Army operational personnel.

These estimates, made by the DNA Intermediate Dose Program (IDP), must be validated for military planners to use them confidently. Because direct validation is impossible, performance decrements caused by an illness with similar symptoms becomes a significant means to check the validity of the estimates for radiation sickness.

Studies of the effects of motion sickness on performance are a good source of independent data, especially on performance degradation due to nausea and vomiting. Studies conducted by the U.S. Navy and Coast Guard directly measured performance decrements of seasick but otherwise healthy military personnel performing a battery of operational tasks. These studies have developed reliable techniques for predicting performance decrement due to motion sickness.

In a study of naval performance, Abrams et al. [1971] administered performance tests along with a motion and mood questionnaire to individuals in a motion simulator. An analysis of these data indicates that 78 percent vomited during the test. Of those who vomited, 50 percent continued to perform their task while 28 percent were too ill to continue. These findings are particularly relevant, since the frequency, duration, and pattern of emesis are much like those reported for individuals experiencing radiation sickness. Although these data suggest an overall relationship between emesis and performance decrement

in military operators, the study related performance decrement to sea state, not directly to the severity of nausea and vomiting.

With this limitation in mind, another study [Wiker, Pepper, and McCauley, 1980] from this series was selected to relate military task decrement directly to the severity of nausea and vomiting. The study of Wiker et al. contains two features that make the comparison of the results with the IDP performance estimates possible. First, the test subjects were rated with a Motion Sickness Symptomatology Severity (MSSS) score that has elements in common with the Radiation Sickness Symptom Severity (RSSS) scales used in the IDP. Second, the Wiker et al. study employed a battery of performance tests in which performance decrement during motion sickness correlated reliably with MSSS score.

Section 2 presents the symptom severity scales for motion sickness and radiation sickness and quantifies the extent of correspondence between the two symptomatologies by an algorithm which maps Radiation Sickness Symptom (RSS) complexes onto the MSSS scale. Section 3 presents the empirical performance data of Wiker et al. and the estimated performance data of the IDP program as functions of MSSS score, allowing a direct comparison of performance degradation caused by common symptomatology. Section 4 gives conclusions.

SECTION 2

MOTION AND RADIATION SICKNESS SEVERITY SCALES AND THEIR RELATIONSHIP

The stimuli which provoke motion sickness are quite different from those that cause radiation sickness. However, in certain ranges of ionizing radiation dose and time-after-dose the human symptom response is quite similar to that for motion sickness. This section quantifies the relationship between the symptomatologies of the two types of sickness through the use of previously developed symptom severity scales. The first two subsections describe symptom severity scales for motion sickness and radiation sickness, respectively. The third subsection gives an algorithm which maps a subset of the Radiation Sickness Symptom (RSS) complexes onto the Motion Sickness Symptom Severity (MSSS) scale.

2.1 MOTION SICKNESS SYMPTOM SEVERITY SCALE.

Onset of motion sickness is characterized by an array of gastrointestinal (e.g., stomach awareness, anorexia, and pronounced lower bowel movements), neurological (e.g., headache, dizziness, and vertigo), and affective state changes (e.g., depression, apathy, and fatigue). The breadth and severity of these initial symptoms vary among individuals. However, a predictable course of symptoms develops with increased severity of motion sickness. Pronounced anorexia is followed by nausea, pallor, malaise, profuse sweating and salivation, drowsiness, and vomiting and retching. If the motion sickness episode is severe or protracted, then fluid and electrolyte imbalances develop, and the subject can go into shock.

Wiker, Kennedy, McCauley, and Pepper [1979] have described a Motion Sickness Symptomatology Severity (MSSS) scale which they have shown to be valid and reliable as a quantitative measure of motion sickness. Their paper gives a detailed description of the MSSS scale along with references to related work leading to the development of the scale. Section 3 below will reference and describe an application of the MSSS

scale in a field study of psychomotor performance changes in men at sea. A brief description of the scale will be given here.

The MSSS scale consists of the integers from 0 to 7. The absence of symptoms corresponds to the integer 0. Emesis during the period of time in question corresponds to the integer 7. The integers 1 through 6 are assigned by first defining three types of symptoms, namely, "major," "minor," and "other," and then specifying combinations of "major," "minor," and "other" symptoms which correspond to each integer.

"Major" symptoms are those such as moderate to severe nausea, retching or profuse sweating. "Minor" symptoms are those such as slight nausea, a beading sweat, or moderate drowsiness. "Other" symptoms are those such as stomach awareness, slight sweating, anorexia, or dizziness.

Table 1, taken from Wiker et al., shows the combinations of symptom types which are assigned to each integer of the MSSS scale. Note that for MSSS = 7, "Experimenter's report of emesis" means that the subject has vomited during task performance.

2.2 RADIATION SICKNESS SYMPTOM SEVERITY SCALES.

Baum, Anno, Young, and Withers [1984] recently presented a description of typical human symptoms in response to prompt doses of ionizing radiation. The acute period of radiation response has an early prodromal phase and a later manifest-illness phase. The onset of the prodromal phase occurs sooner with increasing dose, being about two to four hours after doses of 300 to 530 rads (cGy) free-in-air. The characteristic signs and symptoms are nausea, vomiting, anorexia, and, to a lesser degree, diarrhea. Beginning at doses of about 530 rads (cGy), and as vomiting and diarrhea become severe, fluid loss, electrolyte imbalance, and headache occur. The symptoms of the manifest-illness phase occur later and result primarily from injury to the hemopoietic (blood-forming) and gastrointestinal systems. They include bleeding, infections, fever, ulcerations of the mouth and throat, fainting, and prostration.

Table 1. Diagnostic criteria for levels of motion sickness severity.

MSSS Score	Criteria
7	Experimenter's report of emesis
6	Two major symptoms (including retch and subject's report of emesis)
5	One major and two minor symptoms
4	One major symptom alone or Two minor symptoms or One major and one minor symptom or One minor plus four other symptoms of which two (or more) are stomach awareness, sweating, drowsiness, or pallor (depending on whether pallor is scored)
3	One minor plus other symptoms
2	More than two other symptoms are reported
1	Any symptom related to motion sickness is reported
0	No symptoms are reported

To provide a quantitative description of the symptomatology of both the prodromal and manifest-illness phases of the acute radiation sickness syndrome, the researchers first grouped the symptoms into six categories and then developed a severity scale for each symptom category [Baum et al. 1984; Anno and Wilson, in preparation]. Integers from 1 to 5 specify severity for each category of symptoms. The integer 1 corresponds to no symptoms in that category, and the integer 5 corresponds to the most severe symptoms in that category. Table 2 presents a full listing of the word descriptions for each severity level of the six symptom categories.

Table 2. Word descriptions of the severity levels for the six categories of acute radiation sickness symptoms.

Severity Level	Description
UG: UPPER GI DISTRESS	
1	No effect
2	Upset stomach; clammy and sweaty; mouth waters and swallows frequently
3	Nauseated; considerable sweating; swallows frequently to avoid vomiting
4	Vomited once or twice; nauseated and may vomit again
5	Vomited several times including the dry heaves
LG: LOWER GI DISTRESS	
1	No effect
2	Feels uncomfortable urge to defecate
3	Occasional diarrhea, recently defecated and may again
4	Frequent diarrhea and cramps, defecated several times and will again soon
5	Uncontrollable diarrhea and painful cramps
FW: FATIGABILITY AND WEAKNESS	
1	No effect
2	Somewhat tired with mild weakness
3	Tired, with moderate weakness
4	Very tired and weak
5	Exhausted with almost no strength
HY: HYPOTENSION	
1	No effect
2	Slightly light-headed
3	Unsteady upon standing quickly
4	Faints upon standing quickly
5	In shock: breathes rapidly and shallowly, motionless, skin cold, clammy, and very pale

Table 2. Word descriptions of the severity levels for the six categories of acute radiation sickness symptoms (Concluded).

Severity Level	Description
IB: INFECTION AND BLEEDING	
1	No effect
2	Mild fever and headache--like starting to come down with flu
3	Joints ache, considerable sweating; moderate fever; doesn't want to eat; sores in mouth/throat
4	Shakes and chills and aches all over; difficulty in stopping any bleeding
5	Delirious, overwhelming infections; cannot stop any bleeding
FL: FLUID LOSS AND ELECTROLYTE IMBALANCE	
1	No effect
2	Thirsty and has dry mouth; weak and faint
3	Very dry mouth and throat, headache; rapid heartbeat and may faint with moderate exertion
4	Extremely dry mouth, throat, skin and very painful headache, has difficulty moving; short of breath, burning skin and eyes
5	Prostrate

The set of radiation sickness symptoms typically occurring during a given interval after a given prompt dose of ionizing radiation is termed a Radiation Sickness Symptom (RSS) complex. A six-digit number gives a concise specification of an RSS complex, where the digits represent the severity level of the symptom categories in the order presented in Table 2. For example, the RSS complex represented by 114111 consists of severity level 4 for the fatigability and weakness symptom category and no symptoms in the other categories.

Anno, Wilson, and Dore [1983] have described typical RSS complexes during the first six weeks of radiation sickness following doses in the range from 75 to 4500 rads (cGy) free-in-air. They used a

representative set, consisting of 40 of these RSS complexes, to obtain expert judgments of the effect of radiation sickness on the performance of members of selected Army combat crews. Section 3 discusses these performance estimates. The next subsection compares the RSS complexes with motion sickness symptomatology.

2.3 MAPPING RADIATION SICKNESS COMPLEXES ONTO THE MSSS SCALE.

Researchers have long recognized a parallel between the human symptom response to ionizing radiation exposure and the response involved in motion sickness. We present for the first time a quantitative comparison of symptomatologies.

The similarity of radiation sickness to motion sickness is quite pronounced if bounds are placed on the radiation dose or on the time interval between radiation exposure and symptom occurrence. In particular, few differences in acute symptoms occur for radiation doses less than 150 rads (cGy) free-in-air. Furthermore, for doses less than 800 to 1100 rads (cGy), the symptoms within the first 24 hours after exposure are quite similar to those found with motion sickness. Beyond these limits radiation sickness differs from motion sickness in the severity of diarrhea, the incidence of fever, hematological changes, internal bleeding, infection, and most likely the degree of muscular weakness. Thus, it is expected that certain early radiation sickness symptom (RSS) complexes will correspond closely to states of motion sickness and that other RSS complexes will not correspond at all.

Since the MSSS scale is simpler than the system of six severity scales used to construct the RSS complexes, it is natural to map the RSS complexes onto the MSSS scale. The mapping provides a quantitative expression of the relationship between the symptomatologies of motion and radiation sickness. The mapping will not be one-to-one since several RSS complexes will correspond to the same MSSS score, and, furthermore, certain RSS complexes containing symptoms unrelated to motion sickness cannot be mapped to the MSSS scale.

Mapping the RSS complexes onto the MSSS scale requires two steps. First, radiation sickness symptoms are categorized as either "major," "minor," "other," or "unrelated" in the sense used by Wiker et al. [1979] to describe motion sickness symptoms. Table 3 presents our

Table 3. Categorization of radiation sickness symptoms in terms of motion sickness types

UPPER GASTROINTESTINAL DISTRESS

1. No symptoms

2. Upset stomach (other)
   Clammy and sweaty (other)
   Mouth waters and subject swallows frequently (minor)

3. Nauseated (major)
   Considerable sweating (major)
   Swallows frequently to avoid vomiting (other)

4. Vomited (MSSS = 7)

5. Vomited (MSSS = 7)

LOWER GASTROINTESTINAL DISTRESS

1. No symptoms

2. Feels uncomfortable urge to defecate (other)

3. Occasional diarrhea, recently defecated (other)

4. Frequent diarrhea and cramps (rare in motion sickness - other)

5. (Unrelated)

FATIGABILITY AND WEAKNESS

1. No symptoms

2. Somewhat tired with mild weakness (other)

3. Tired, with moderate weakness (minor)

4. Very tired and weak (major)

5. (Unrelated)

Table 3. Categorization of radiation sickness symptoms in terms of motion sickness types (Concluded).

HYPOTENSION	
1.	No symptoms
2.	Slightly light-headed (other)
3.	Unsteady upon standing quickly (other)
4.	(Unrelated)
5.	(Unrelated)
INFECTION AND BLEEDING	
1.	No symptoms
2.	Mild fever and headache (other)
3.	(Unrelated)
4.	(Unrelated)
5.	(Unrelated)
FLUID LOSS AND ELECTROLYTE IMBALANCE	
1.	No symptoms
2.	Thirsty and has dry mouth, weak and feels faint (other)
3.	(Unrelated)
4.	(Unrelated)
5.	(Unrelated)

categorization of the radiation sickness symptoms from Table 2. Second, for each RSS complex, the numbers of these motion sickness symptom types are tallied, and an MSSS score is assigned according to the definitions of Table 1. Table 4 lists the resulting MSSS scores for 40 RSS complexes.

It was possible to map 27 out of the 40 radiation sickness complexes onto the MSSS scale. A close inspection of the relationship between MSSS score magnitude and radiation sickness complex structure shows that the MSSS score is sensitive primarily to shifts in upper gastrointestinal symptom severity (i.e., the first RSSS digit).

The MSSS score is less sensitive to certain symptoms found with radiation sickness. These symptoms are usually either mild in nature, unvaried in severity, or not reliably encountered during a motion sickness episode. Hence, the MSSS score does not change until several of these "other" symptoms are accumulated. For this reason, a subject must at times advance through several radiation sickness symptom (RSS) complexes before producing a change in the MSSS score.

The quantitative relationship between the symptomatologies of radiation sickness and motion sickness presented in this section provides an immediate basis for comparing measured performance decrements of seasick subjects to the estimated performance degradation due to radiation sickness. In addition, the algorithm for mapping radiation sickness complexes onto the motion sickness symptom severity scale provides a framework for future improvements as symptomatology descriptions evolve and additional human performance data is acquired.

Table 4. Radiation sickness symptom complexes and their associated MSSS scores.

Symptom Complex	MSSS Score	Symptom Complex	MSSS Score
111121	1	314111	6
111131	*	314112	6
		314113	*
112121	1	315113	*
112131	*	334231	*
113111	1		
		411111	7
113121	3	412111	7
113131	*	413111	7
114111	4	414111	7
114112	4	414112	7
123111	3	415314	*
211111	3	513111	7
212111	3	514111	7
213111	4		
214112	4	515223	*
214113	*	515311	*
224111	4	515431	*
311111	6	521111	7
312111	6		
313111	6	525111	*
313112	6	535111	*

* Symptom complex has elements not characteristic of motion sickness

SECTION 3

A COMPARISON OF PERFORMANCE DEGRADATION FOR MOTION AND RADIATION SICKNESS

This section compares empirical performance data for U.S. Coast Guardsmen suffering motion sickness and estimated performance data for members of certain U.S. Army combat crews were they to suffer acute radiation sickness. The analysis is intended to place the comparison on a quantitative basis and to examine whether the motion sickness data supports the validity of the estimates of performance degradation from radiation sickness.

The first two subsections summarize the performance data for motion and radiation sickness and present regression analyses of performance vs. MSSS score. A final subsection compares the performance data for the two types of sickness.

3.1 EMPIRICAL PERFORMANCE DEGRADATION FROM MOTION SICKNESS.

Wiker, Pepper, and McCauley [1980] reported findings from a joint U.S. Coast Guard and Navy study of human response to ship motion and motion sickness (Kaimalino Sea Trials or KAST). Researchers measured psychomotor performance on a battery of tasks both dockside and at sea. During all trials the subjects were monitored for seasickness signs and symptoms so that an MSSS score could be associated with each performance measurement.

We selected four tasks, namely, critical tracking (CT), code substitution (CS), navigation plotting (NP), and complex counting (CC), from the KAST task battery for use in this report. Appendix A briefly describes the four tasks. Appendix A also includes the results of regression analyses of the task performance scores vs. MSSS score.

For performance degradation on the Army combat crew tasks from radiation sickness, performance was expressed as a number from .0 to 1.0, where 1.0 represents the "usual level of performance" for a well person and .0 represents "could not do it." Performance levels between .0 and 1.0 were calculated by dividing the "usual time" to do a task by the longer "time when sick." [Anno et al., 1983]. The KAST motion

sickness study used various measures of performance. We selected the four tasks listed above based on the reasonableness of converting their performance measurement scores to a .0 to 1.0 scale.

Table 5 presents the regression line equations for performance vs. MSSS score on the KAST tasks converted to a scale of .0 to 1.0 for performance. The complex counting task is already reported as a percent score in Appendix A, so that formula was simply divided by 100. The other three were normalized to performance 1.0 at MSSS = 0 (i.e., at no symptoms of motion sickness). The equations are plotted in Fig. 1.

Table 5. Regression line equations for performance vs. MSSS score on the KAST tasks.

Critical Tracking

$CT = 1. - 0.0400 \times MSSS$

Code Substitution

$CS = .1 - 0.058 \times MSSS$

Navigation Plotting

$NP = 1. - 0.102 \times MSSS$

Complex Counting

$CC = 1.426 - 0.4213 \times MSSS + .0366 \times (MSSS)^2$

The complex counting task is peculiar in that a quadratic form was required to describe a small increase in performance as the motion sickness severity increased from MSSS = 6 to MSSS = 7. The experimenters speculate that a momentary relief of motion sickness symptoms after emesis may have allowed some improvement in performance for this particular task relative to the pre-emesis performance represented by MSSS = 6.

3.2 ESTIMATED PERFORMANCE DEGRADATION FROM RADIATION SICKNESS.

Using descriptions of radiation sickness complexes and their own expert judgment, Army operational personnel estimated the performance

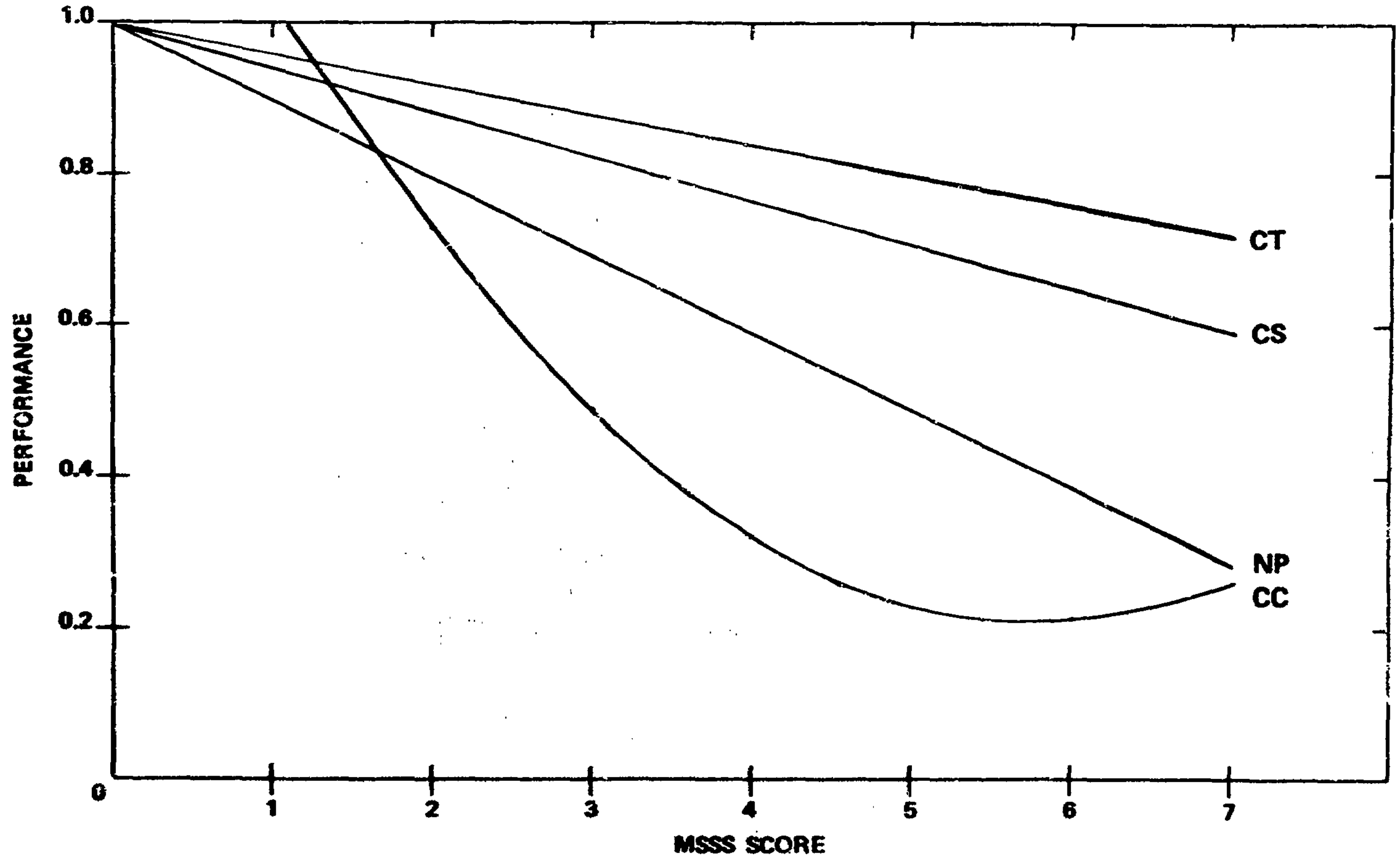

Figure 1. Regression analysis results for performance degradation from motion sickness for four tasks from the KAST trials. See text for key to abbreviations.

levels of individual Army combat crewmembers suffering from acute radiation sickness. They made estimates for 15 different crewmembers of field artillery gun crews, field artillery fire direction center (FDC) crews, tank crews, and antitank guided missile (improved TOW vehicle) crews.

Glickman, Winne, Morgan, and Moe [1983] described the study and reported initial results. Anno, Wilson and Dore [1983] reported details of this method, the data, and final results. Tables 13-27 of the latter report provide individual performance levels for each crewmember and each radiation sickness symptom (RSS) complex. Performance levels used here are from the "Actual Value" column, that is, the average performance as calculated directly from the questionnaire responses.

With these estimated performance levels for each RSS complex and with the mapping of RSS complexes to the MSSS scale as given in Table 5 above, plots of estimated crewmember performance vs. MSSS score may be constructed for each of the 15 Army crew positions. Figures 2-16 show these plots.

As discussed in Sec. 2, the mapping from RSS complexes to the MSSS case is not a single-valued function. For example, eight of the RSS complexes translate to MSSS = 7. The resulting spread in performance estimates at each MSSS level is apparent in the figures. This occurrence of several RSS complexes at a single MSSS level is consistent with the usage of the MSSS scale in motion sickness. Even for motion sickness, several different combinations of symptoms may correspond to a given MSSS level.

Figures 2-16 show a linear regression line constrained to give performance of 1.0 at MSSS = 0 (no symptoms) plotted with a 2-σ line on with side. The reader may verify that there are significant variations of estimated performance correlated with MSSS score even without the constraint at MSSS = 0.

Appendix B lists the slope of the regression lines with standard errors for each crew position. Appendix B also lists the mean estimated performance and standard error at each MSSS level.

Position 1

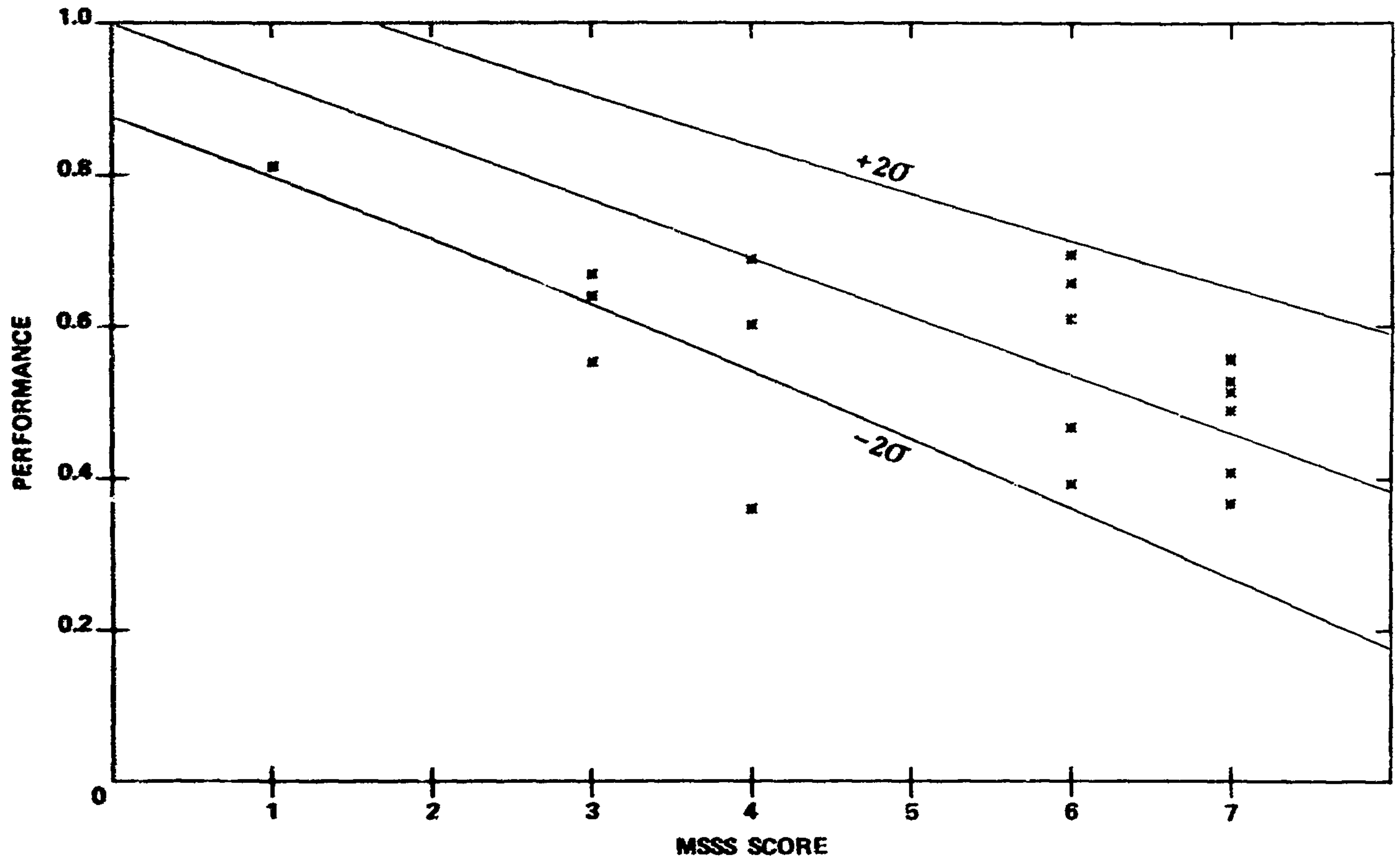

Figure 2. Relationship between MSSS score and estimated performance, gun crew chief of section.

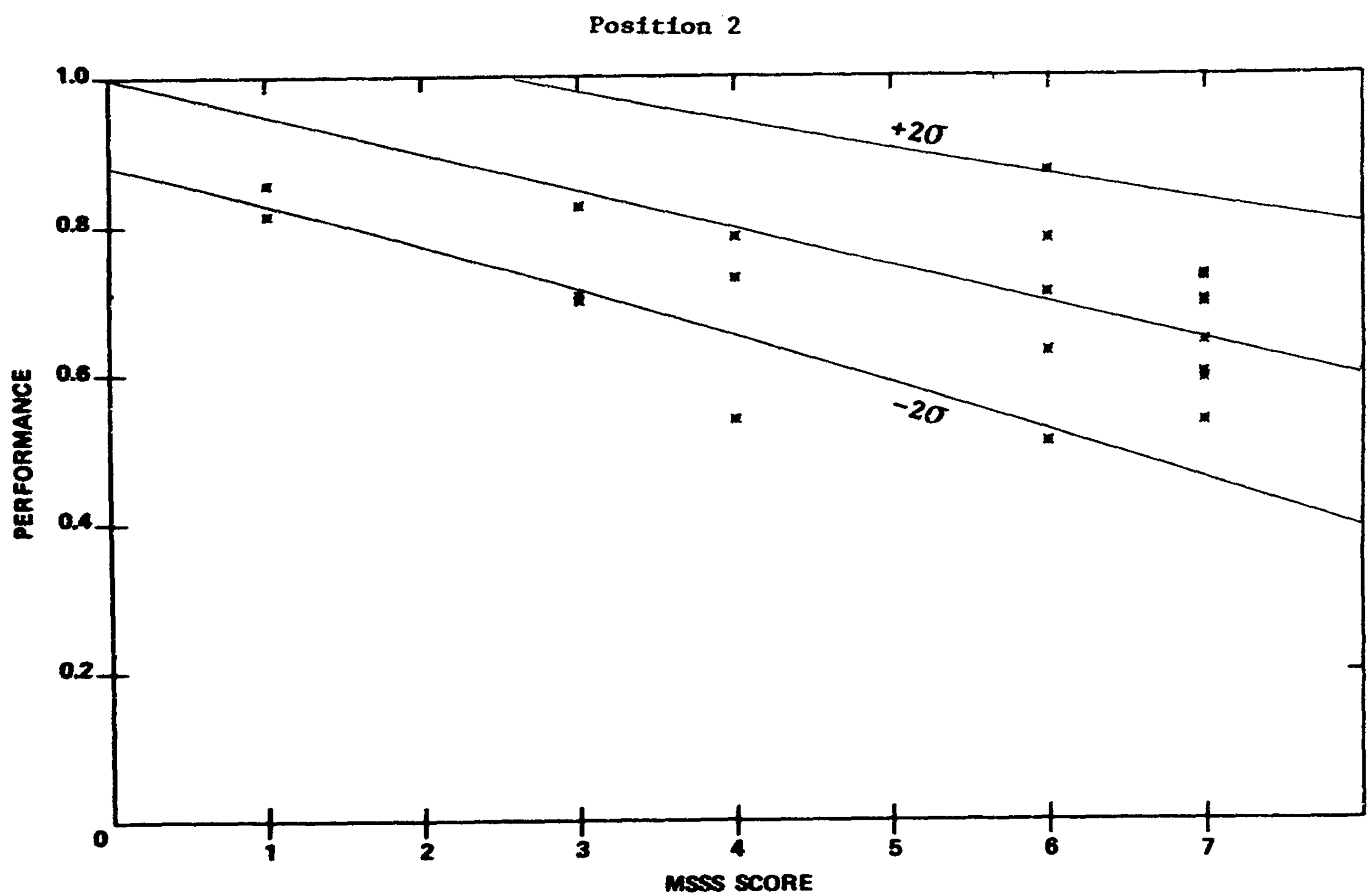

Figure 3. Relationship between MSSS score and estimated performance, gun crew gunner.

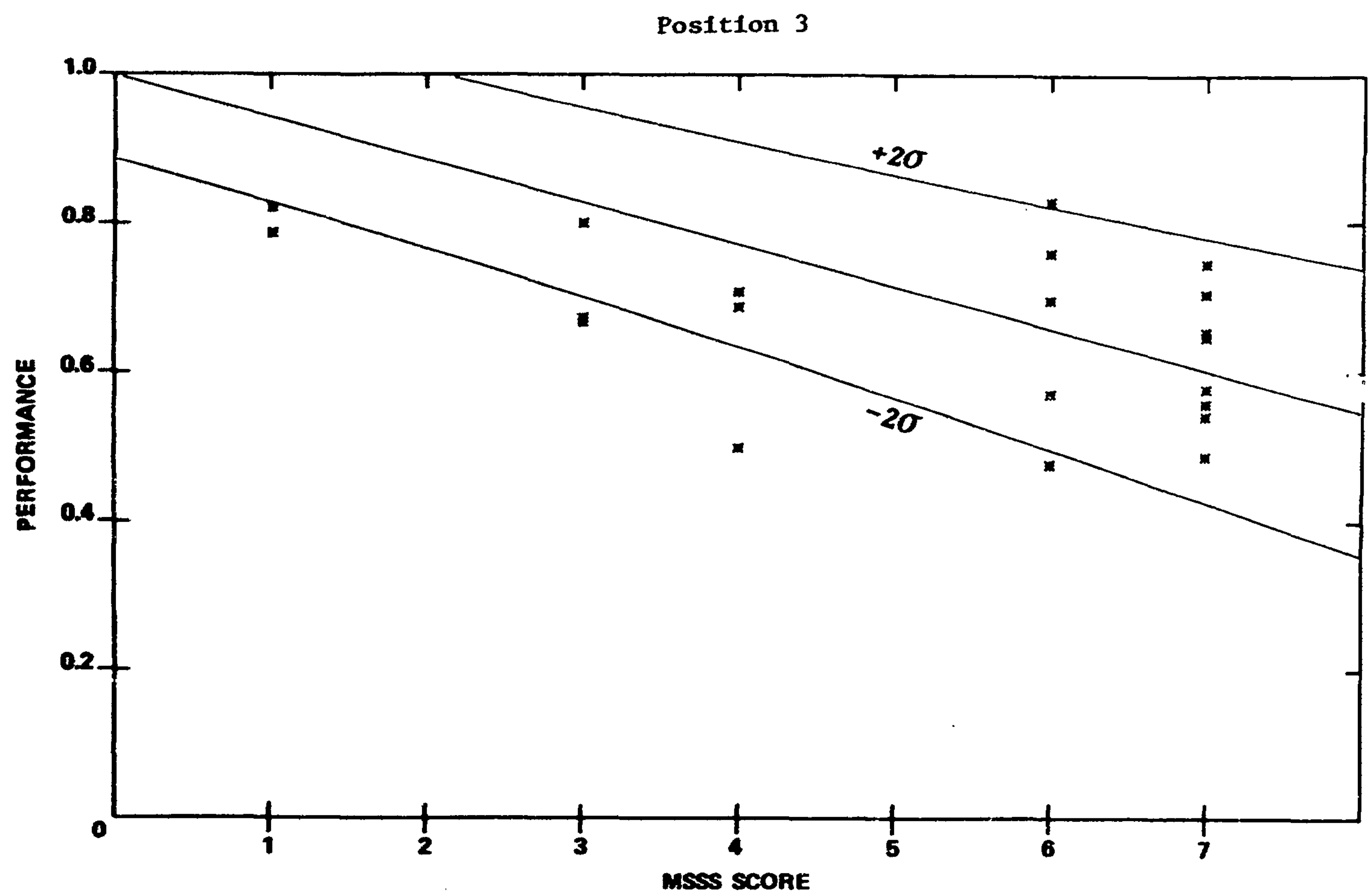

Figure 4. Relationship between MSSS score and estimated performance, gun crew assistant gunner.

Position 4

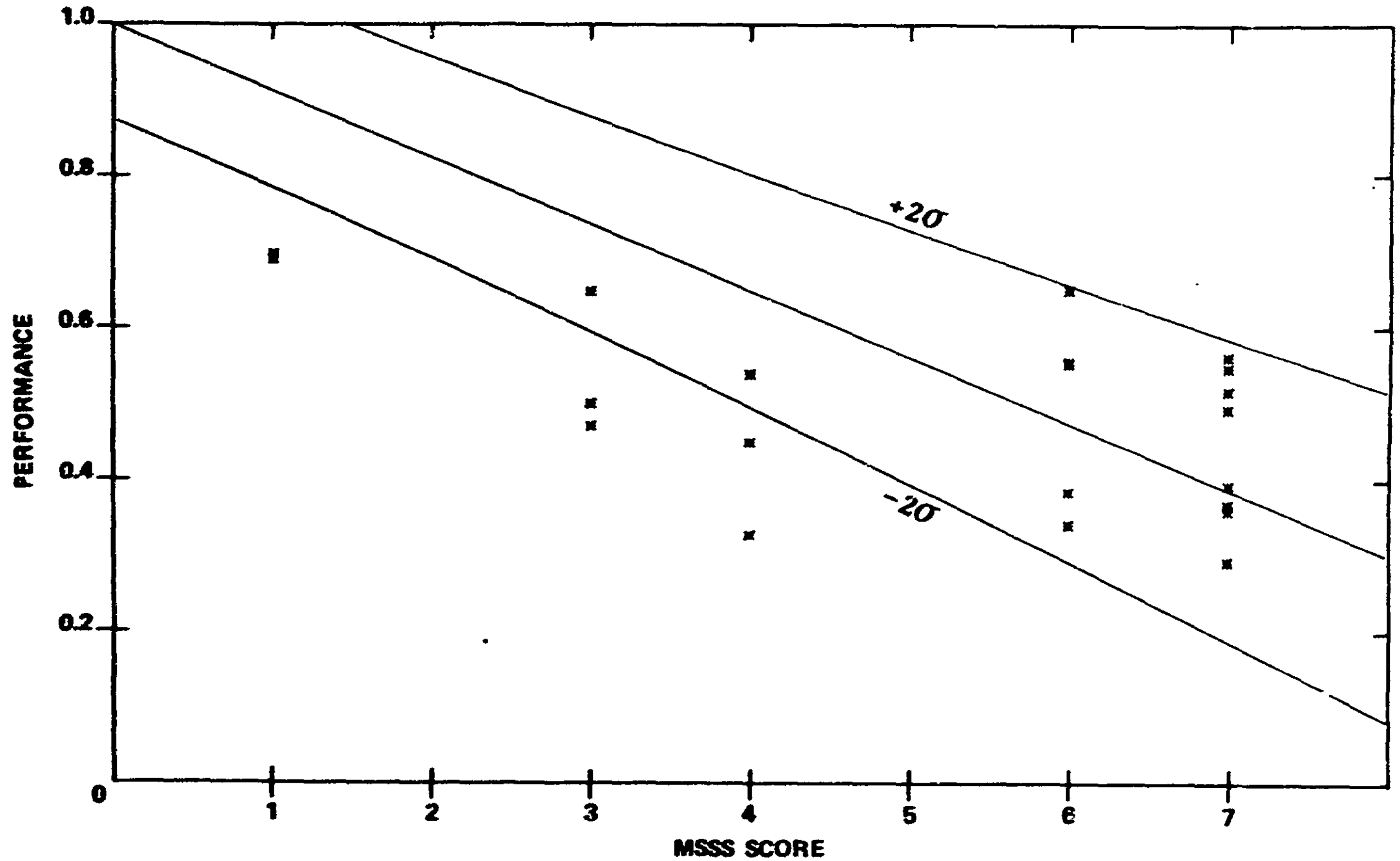

Figure 5. Relationship between MSSS score and estimated performance, gun crew loader.

Position 5

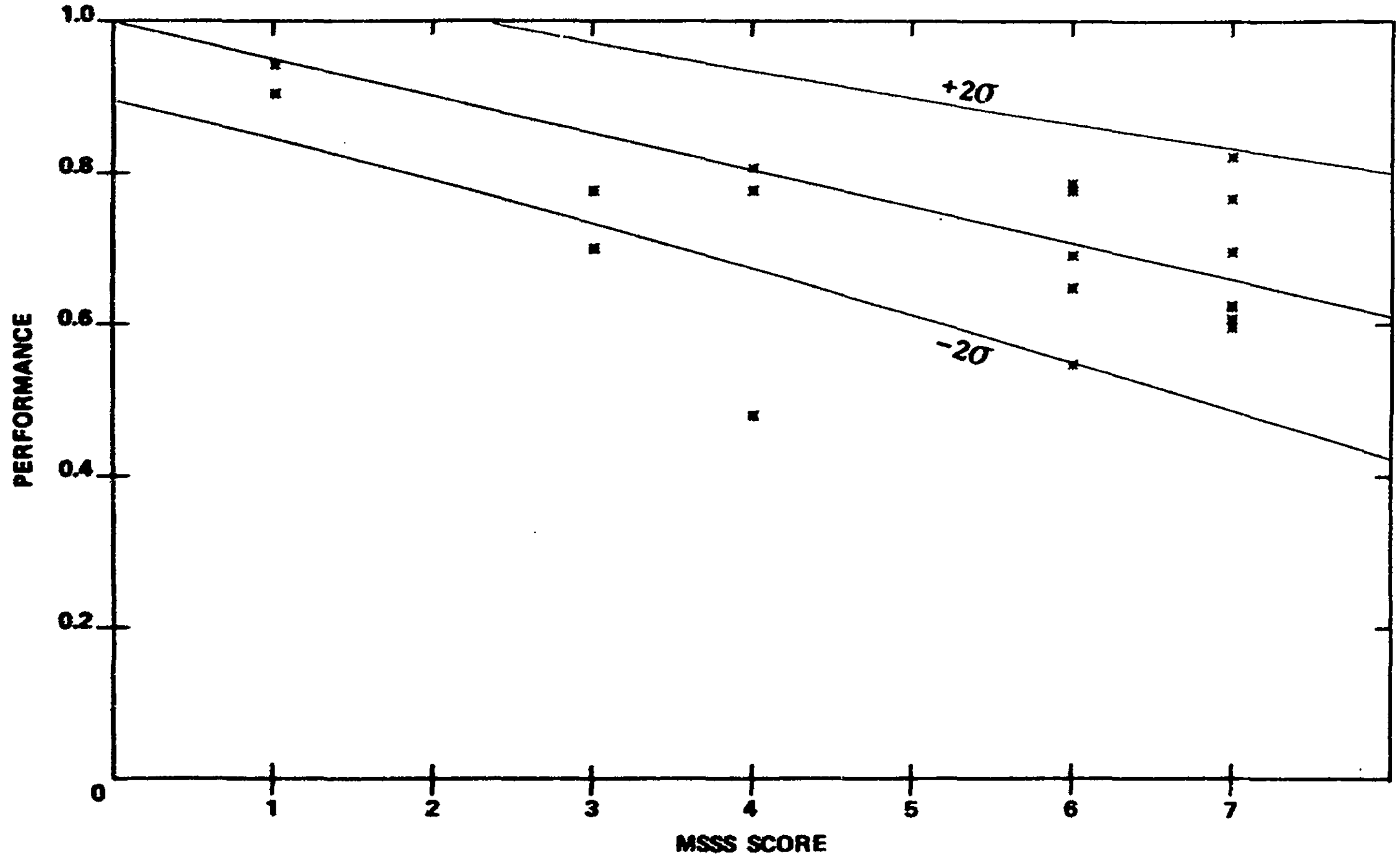

Figure 6. Relationship between MSSS score and estimated performance, FDC crew fire direction officer.

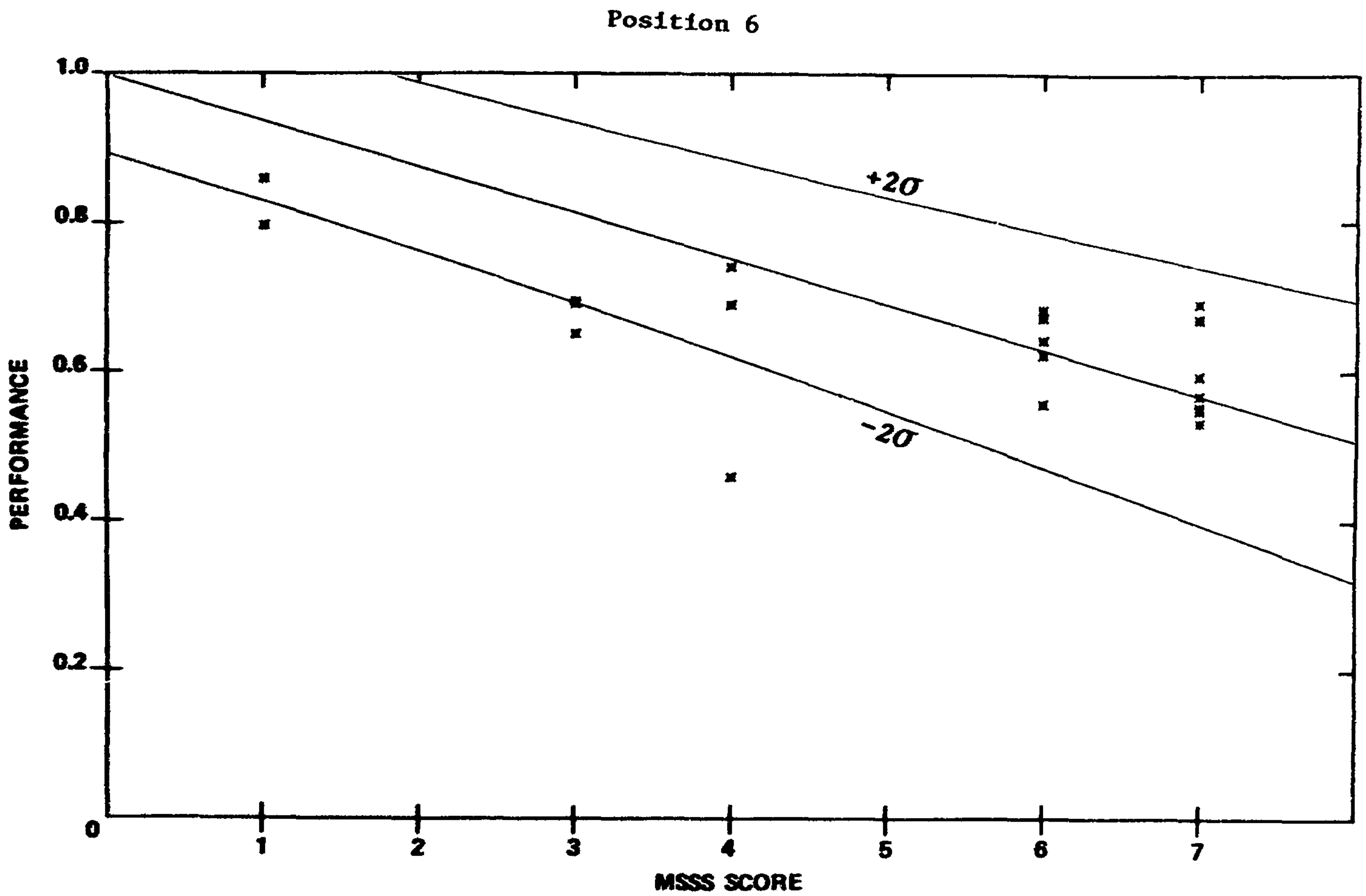

Figure 7. Relationship between MSSS score and estimated performance, FDC crew horizontal control operator.

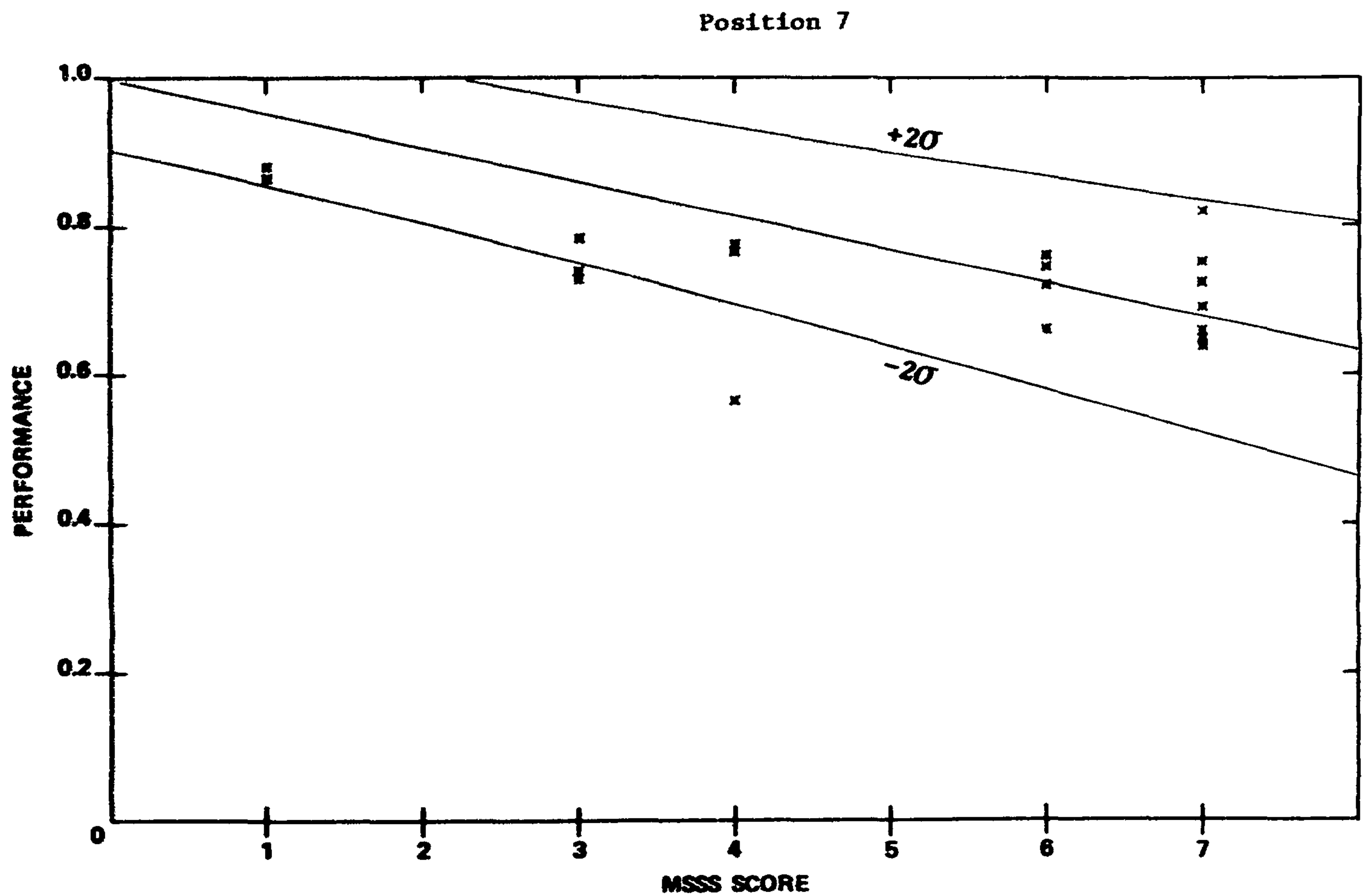

Figure 8. Relationship between MSSS score and estimated performance, FDC crew computer.

Position 8

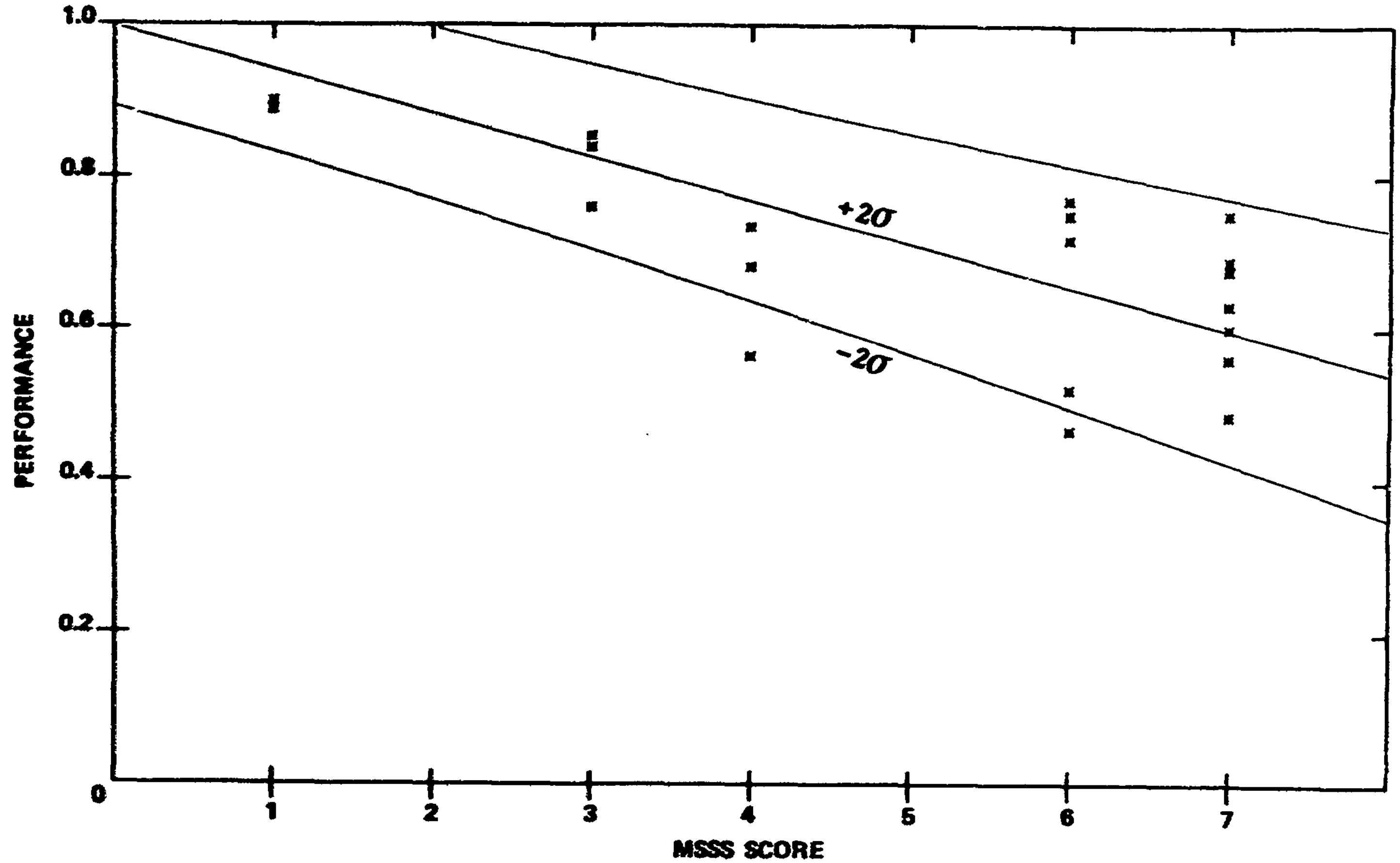

Figure 9. Relationship between MSSS score and estimated performance, tank crew commander.

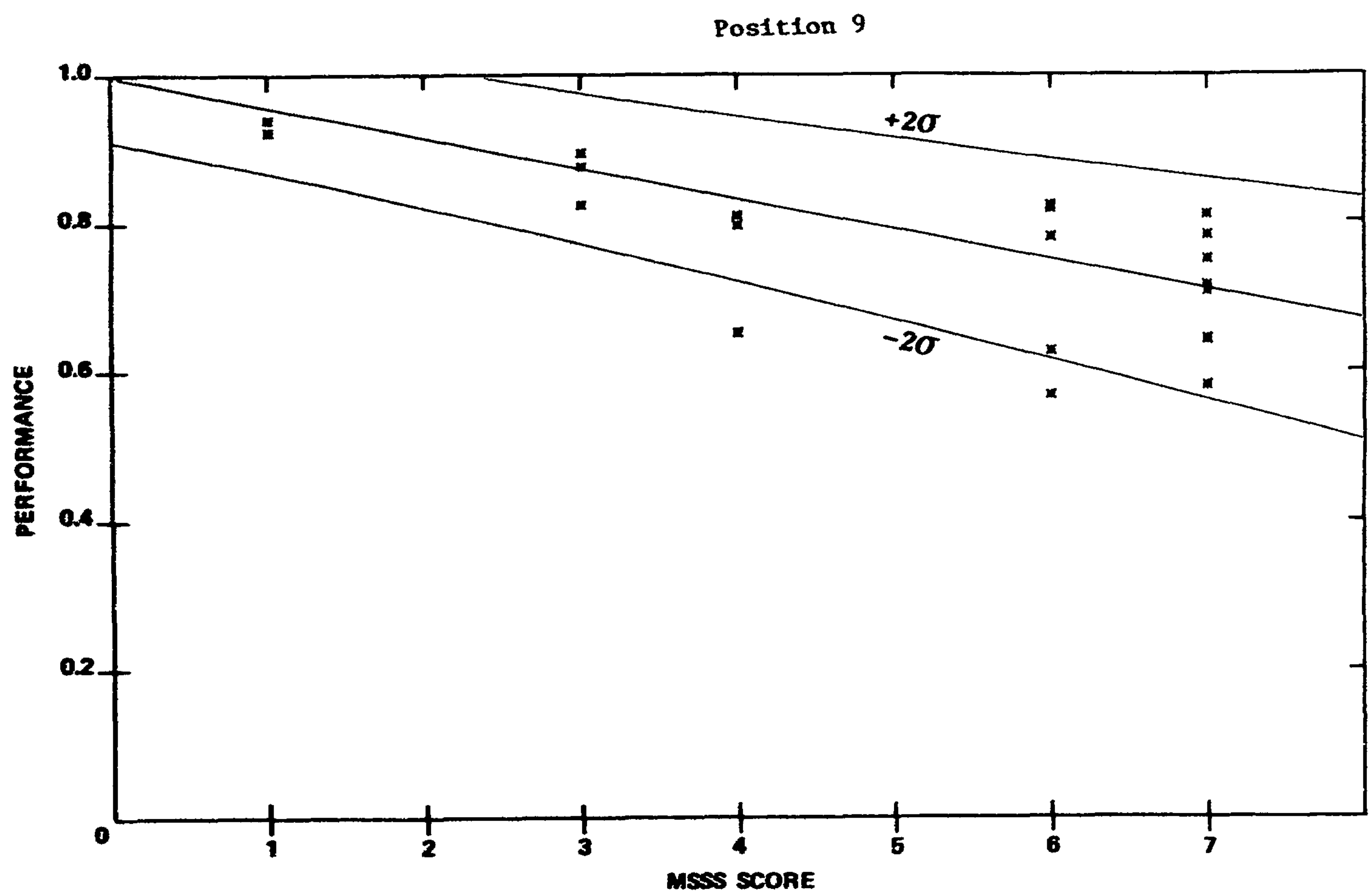

Figure 10. Relationship between MSSS score and estimated performance, tank crew gunner.

Position 10

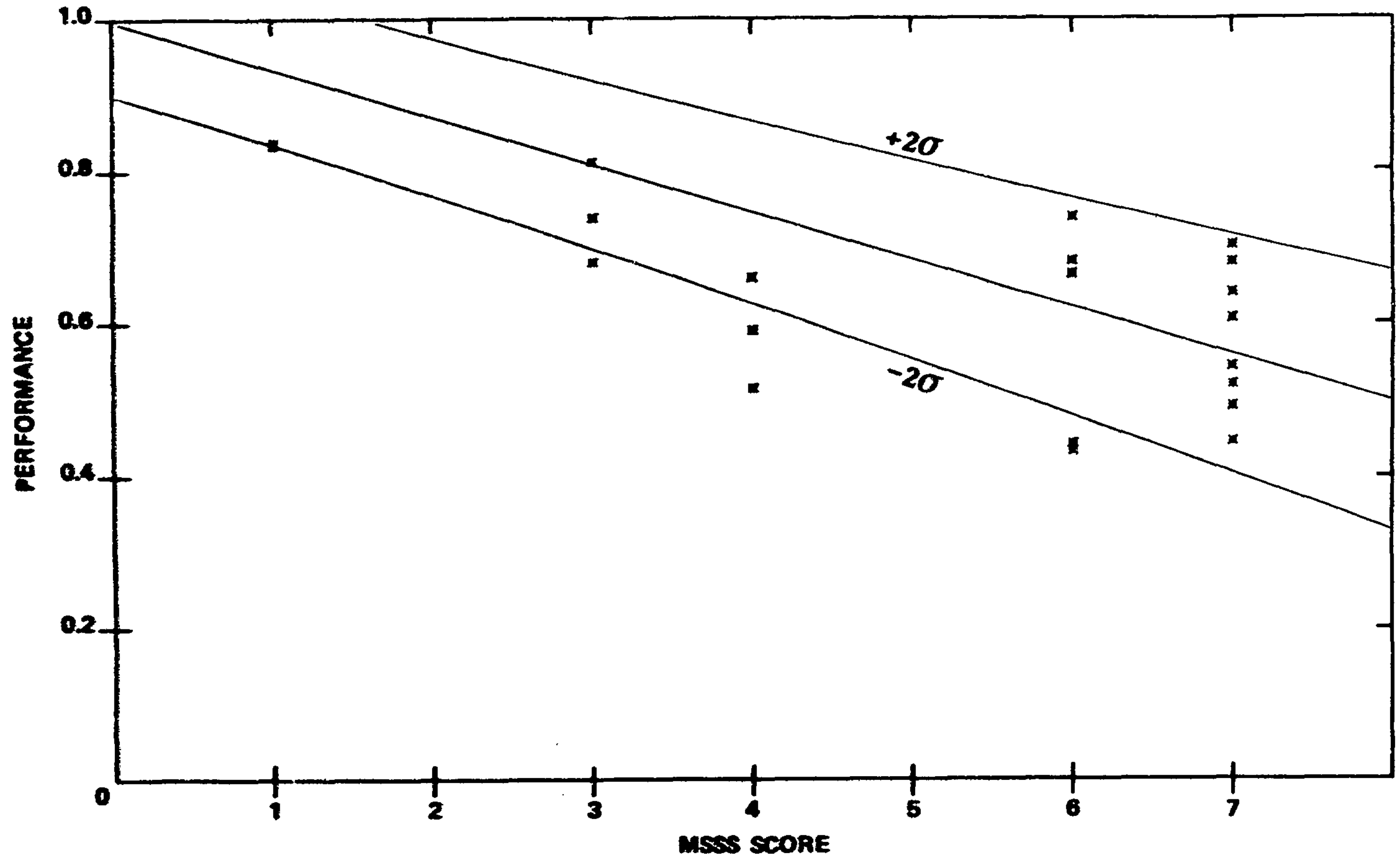

Figure 11. Relationship between MSSS score and estimated performance, tank crew loader.

Position 11

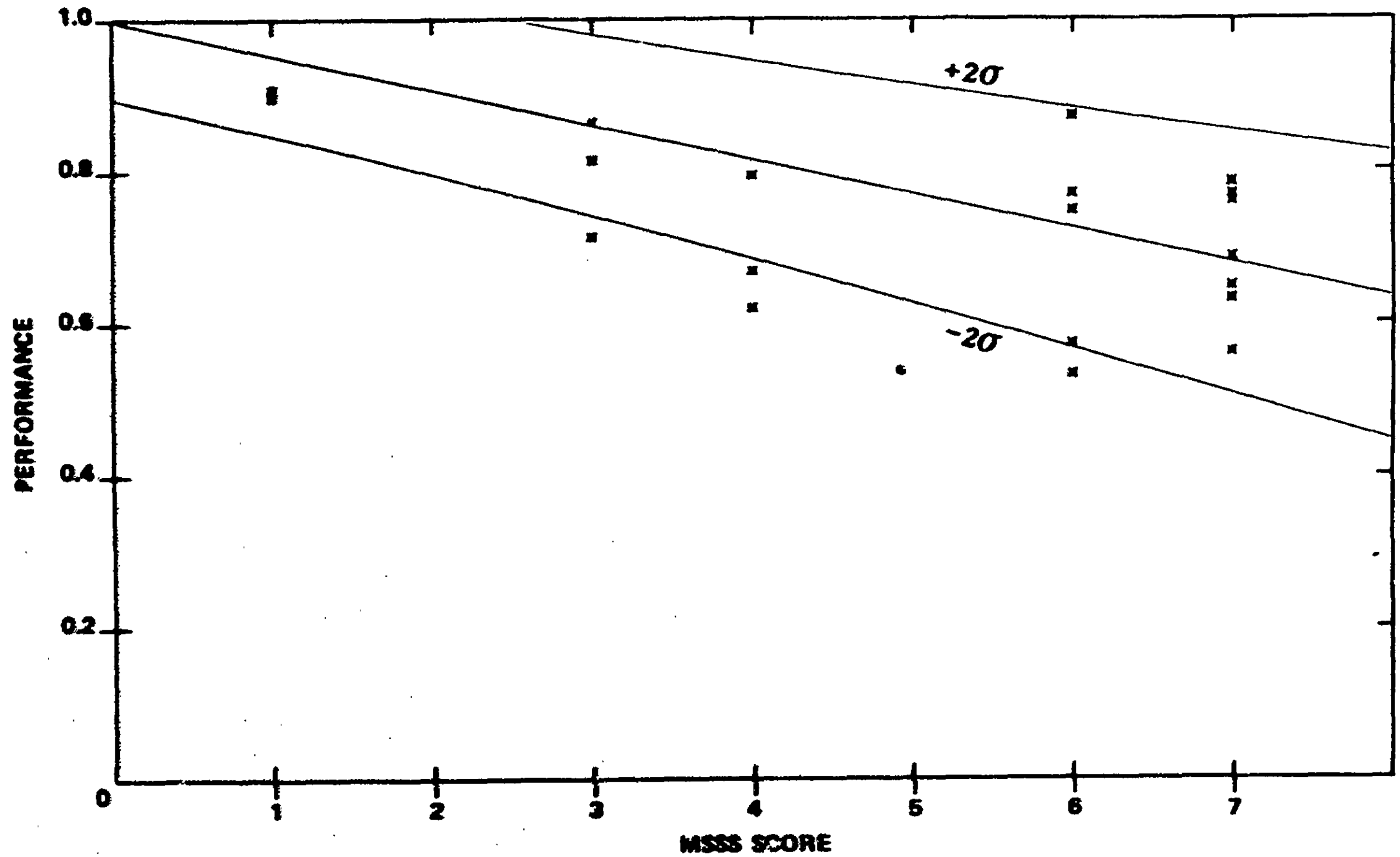

Figure 12. Relationship between MSSS score and estimated performance, tank crew driver.

Position 12

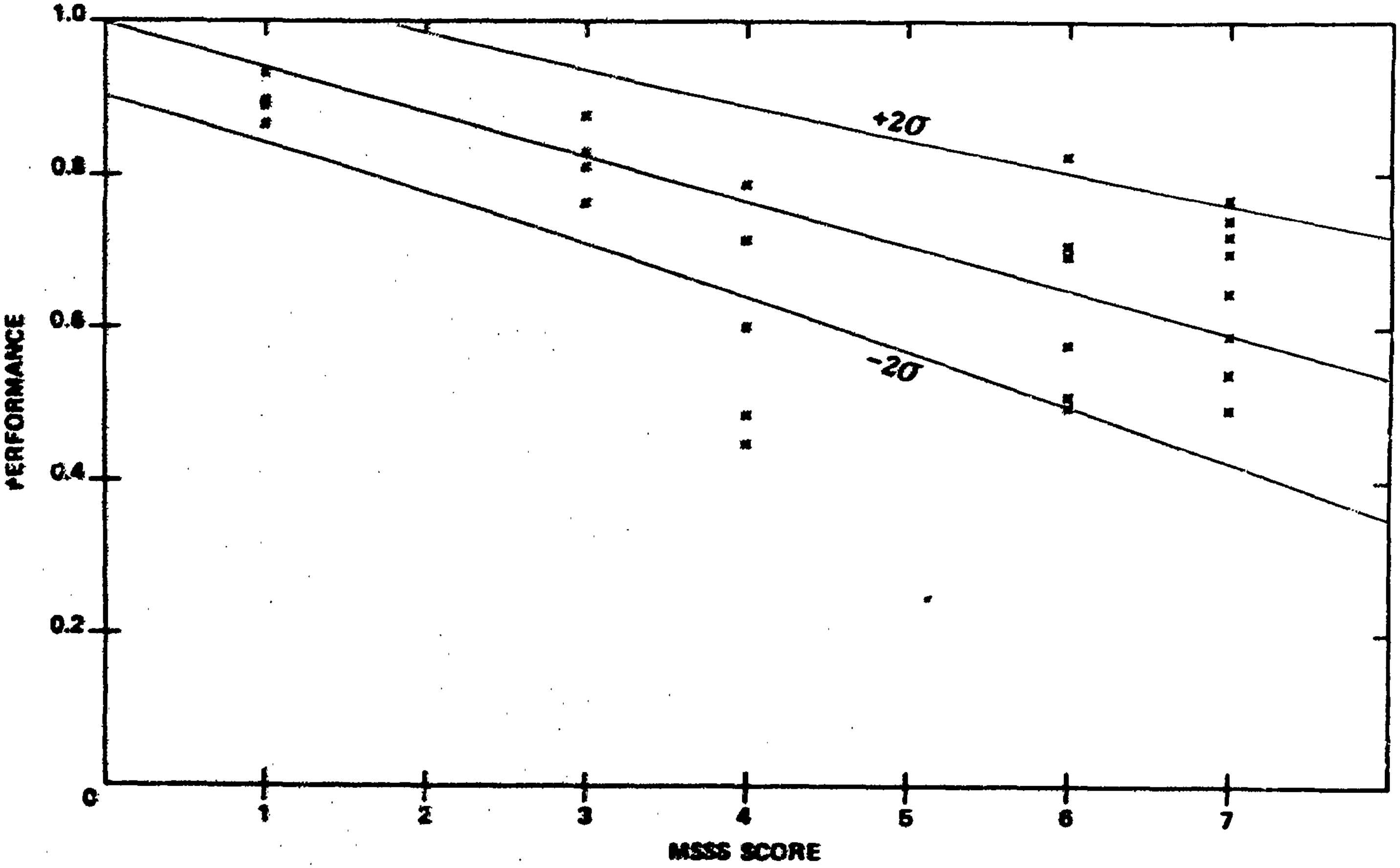

Figure 13. Relationship between MSSS score and estimated performance, TOW crew squad leader.

Position 13

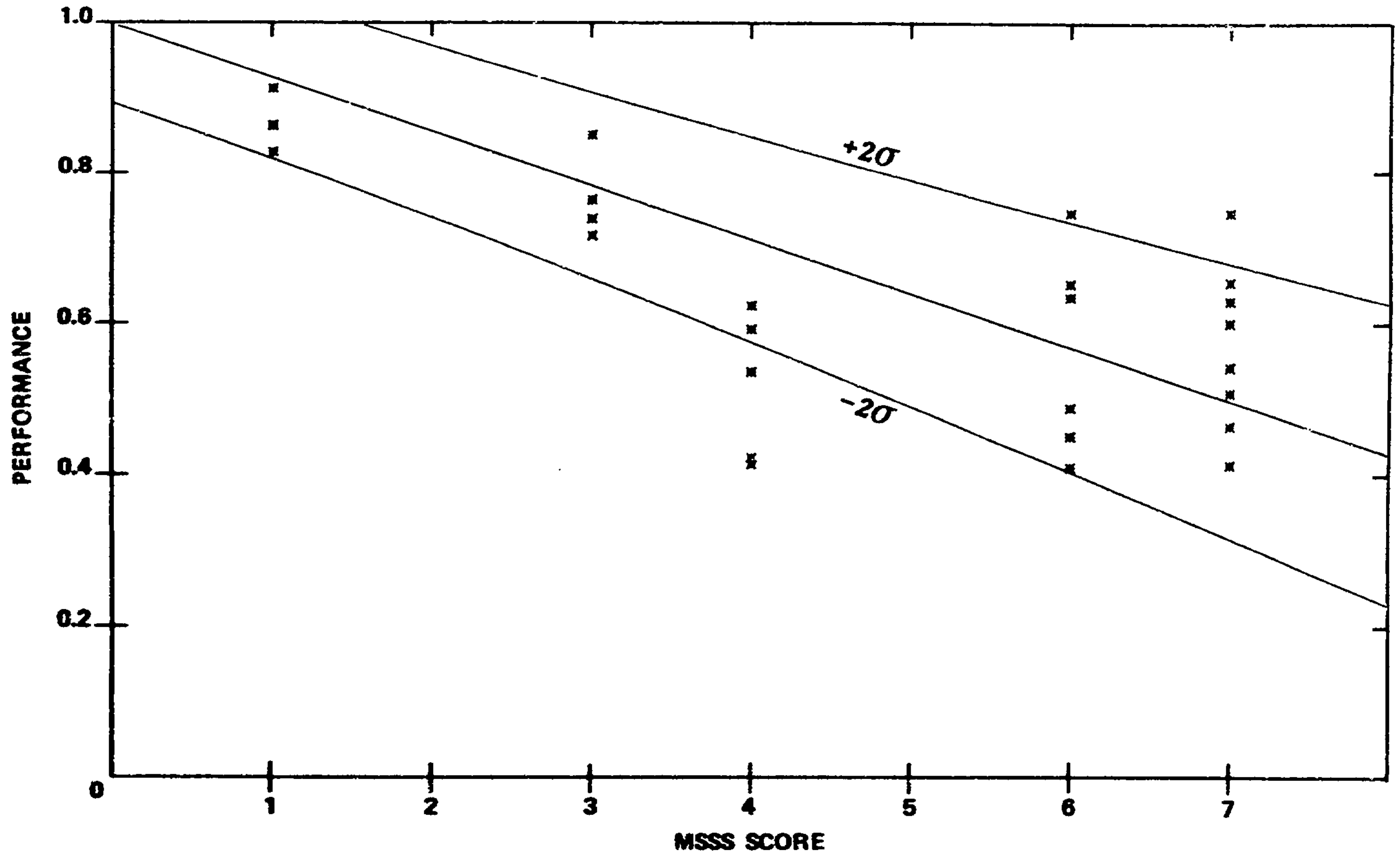

Figure 14. Relationship between MSSS score and estimated performance, TOW crew gunner.

Position 14

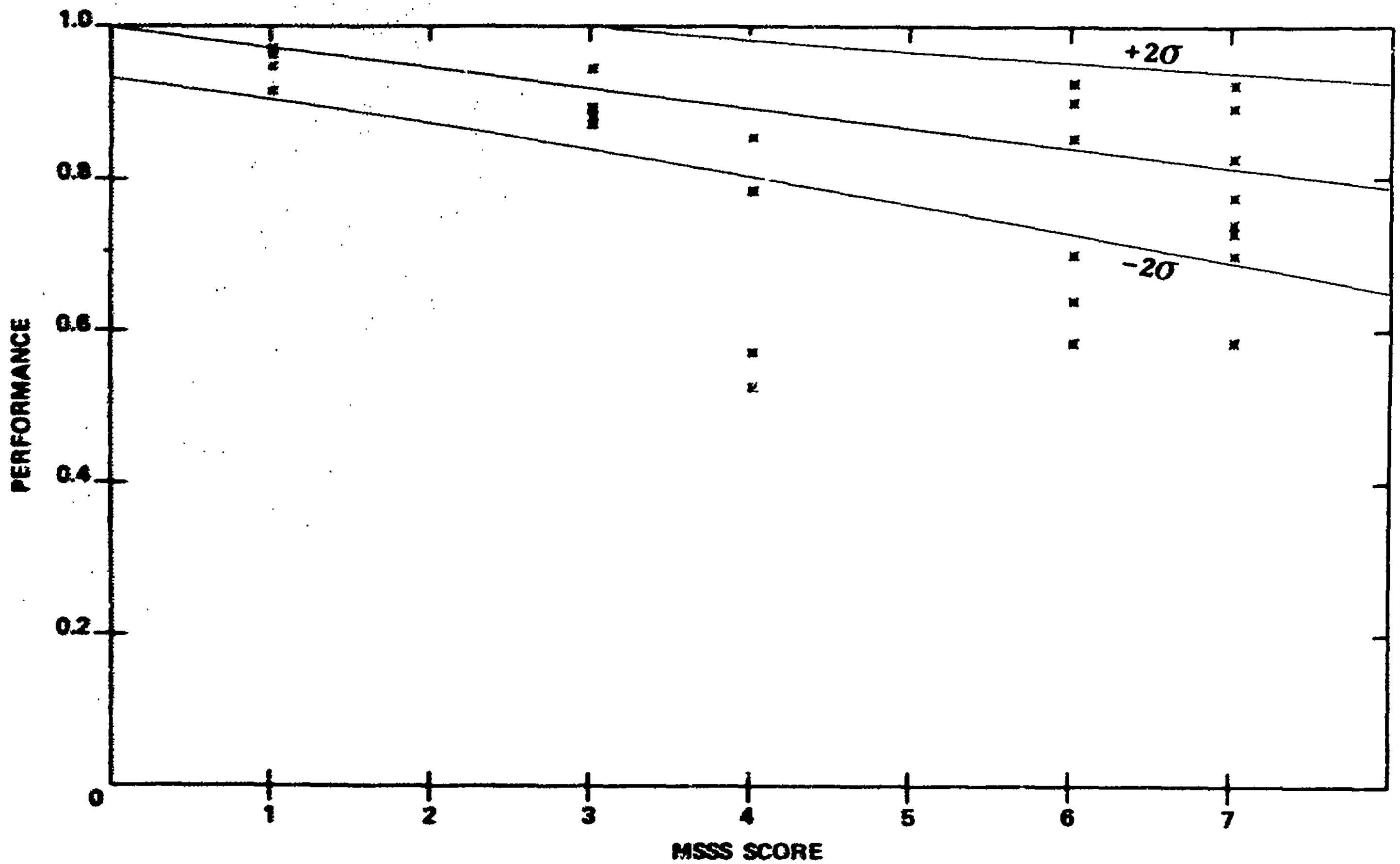

Figure 15. Relationship between MSSS score and estimated performance, TOW crew driver.

Position 15

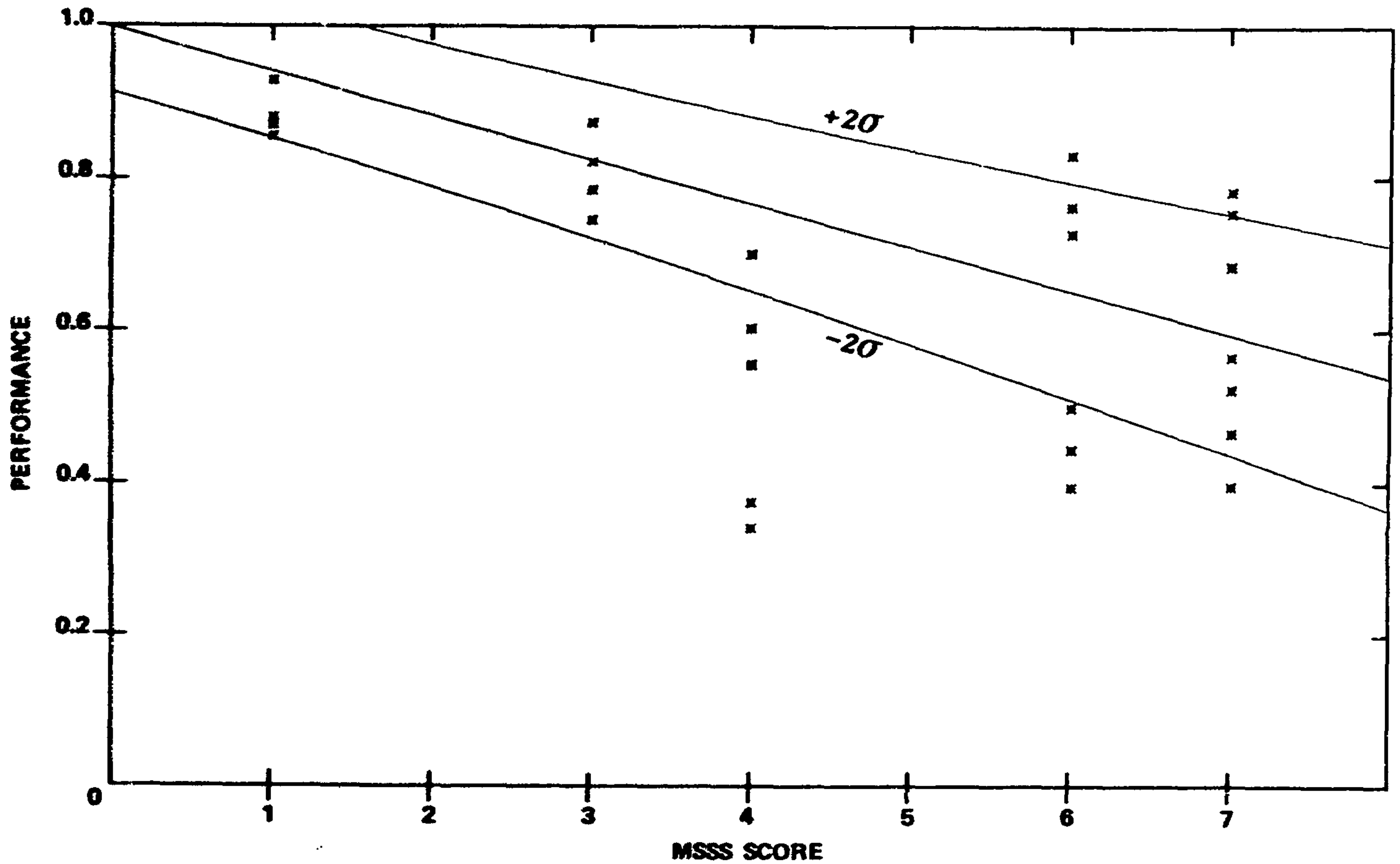

Figure 16. Relationship between MSSS score and estimated performance, TOW crew loader.

The data in Figs. 2-16 could be analyzed in more detail. For example, it is apparent that a quadratic curve would fit the data a little better in many cases. It is not likely, however, that the accuracy of the data warrants such detailed analysis. Furthermore, the conclusions reached in the following discussion would be unchanged.

3.3 COMPARISON OF PERFORMANCE DEGRADATIONS.

When comparing the empirical performance decrements caused by motion sickness with the estimated performance decrements for radiation sickness, planners must keep in mind that only in a few cases were the tasks examined in the KAST experiment directly comparable with those tasks addressed in the Army questionnaire. However, manual control performance (e.g., Critical Tracking, and Navigation Plotting), visual search (e.g., Code Substitution), and short-term memory (e.g., Complex Counting and Code Substitution) are used in the majority of the Army tasks addressed in the questionnaire. Furthermore, the usefulness of the MSSS scale itself is as a broad indicator of symptom severity rather than as a detailed specifier of symptoms. Thus, comparisons and conclusions of a suitably general nature should be valid.

A rank correlation test can statistically measure the validity of the questionnaire method of estimating relative performance degradation. A comparison is made of two independent rankings of those radiation sickness complexes which can be mapped onto the MSSS scale. As shown by Wiker, Pepper, and McCauley [1980], the MSSS score correlates well with performance degradation due to motion sickness. Therefore, the MSSS score for each complex may be used to rank order the set of complexes with respect to measured performance degradation. On the other hand, the performance estimates from the Army questionnaires may also be used to rank order the set of complexes. This ordering is with respect to the questionnaire respondents' judgment of the relative performance degradation caused by different symptom complexes. The rank order generated by the MSSS score is assumed to be valid, so that a correlation test between the two rank orders is a validity check of the questionnaire procedure for estimating relative performance degradation.

Glickman, Winne, Morgan, and Moe [1983] found the rank orders generated for all 15 Army crew positions to be well correlated with each other. For present purposes, we consider the tank crew gunner position

as representative. A Spearman rank correlation coefficient was calculated for the 21 radiation sickness complexes which can be mapped to the MSSS scale. The order given by the MSSS scores and the order given by the performance estimates [Table 21 of Anno, Wilson, and Dore, 1983] provided a Spearman rank correlation coefficient of 0.77. The correlation indicates that the IDP procedure for estimating the relative performance degradation from different radiation sickness complexes is valid.

To facilitate further comparison, the performance degradation results for motion sickness are plotted in Fig. 1 on the same scale as the estimated degradations from radiation sickness in Figs. 2-16.

Estimated performance degradation rates for the Army crewmembers obtained from questionnaire data are generally consistent with decrements measured in Critical Tracking (CT) and Code Substitution (CS) tasks during episodes of motion sickness. However, decrements were more pronounced for the Navigation Plotting (NP) and Complex Counting (CC) tasks. These results are reasonable given the very brief referent task completion times of a few to 60 seconds stipulated on the Army questionnaire. KAST tasks which required performance durations of less than 1 or 2 minutes (e.g., CT and CS tasks), suffered much smaller decrements than tasks which required over 9 minutes of sustained performance (e.g., NP and CC tasks). This difference illustrates the importance of task duration in estimating performance level under stress conditions.

Characteristically, subjects suffering from severe nausea would perform for a short period of time, cease performance, then continue performing for another interval, and so on. If the task was short enough, breaks in task performance were not usually observed. This observation corroborates higher estimates for Army crewmember performance where relatively brief tasks closely resembled the Navigation Plotting task (e.g., the FDC crew).

Figure 17 summarizes Figs. 1-16. The Figure presents the regression line slopes of performance vs. MSSS score in histogram form for both the KAST motion sickness data and the Army performance estimates. The slope coefficients represent the rate of performance degradation with increasing MSSS score. As discussed above, the Army estimates for radiation sickness tend to cluster around the KAST tasks (CT and CS) which have task completion times comparable to those of the Army tasks.

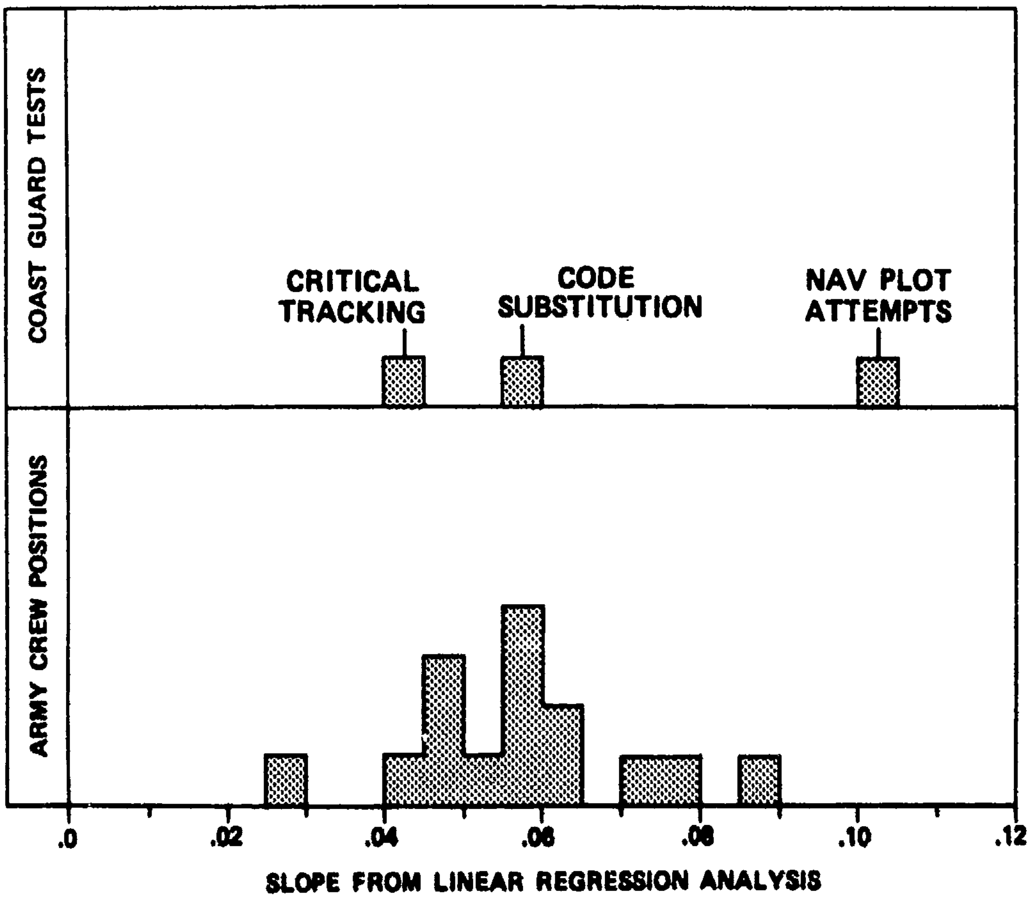

Figure 17. Slope coefficients representing the rate of performance degradation with increasing MSSS level.

A measure of the consistency of two data sets can be made using a chi-squared test. Each of the four curves for the KAST tasks shown in Fig. 1 was compared in turn with the performance estimates for each of the Army tasks. The data for the Army tasks averaged over complexes with the same MSSS number appear in Appendix B. The average performance and its standard deviation are given for each MSSS score that has corresponding radiation sickness symptom complexes, so there are five data points for each chi-squared calculation. Table 6 shows the chi-squared values for all the comparisons.

For five degrees of freedom, a confidence level of 5 percent occurs at a chi-squared value of 11. Table 6 shows that for 14 out of 15 of the Army crew positions, the best matches (minimum chi-squared) are with either the CT or CS KAST tasks. The only exception is the gun crew loader, whose task is physically quite demanding.

Table 6. Chi-squared values (five degrees of freedom) comparing Army crew degradation estimates with the regression analysis results for performance degradation from seasickness during the KAST trials.

Army Crew Position	KAST Task			
	CT	CS	NP	CC
Gun Crew				
Chief of Section	14	5	7	16
Gunner	2	2	25	48
Assistant Gunner	4	2	23	42
Loader	22	11	6	12
Fire Direction Center Crew				
Fire Direction Officer	2	2	31	51
Horizontal Control Operator	7	2	20	38
Computer	2	4	41	74
Tank Crew				
Commander	4	1	21	42
Gunner	1	4	50	89
Loader	9	2	22	43
Driver	1	3	34	60
TOW/ITV Crew				
Squad Leader	5	2	22	46
Gunner	12	4	11	26
Driver	5	8	102	162
Loader	7	4	26	52

SECTION 4

DISCUSSION AND CONCLUSIONS

The first goal of this report was to quantify the relationship between the symptomatologies of motion sickness and acute radiation sickness. Researchers have long recognized a .parallel but lacked a quantitative method of comparison. The independent development of symptom severity scales for the two sicknesses provided the necessary groundwork for the successful method of comparison developed in our research. This report makes available for the first time an algorithm for relating symptomatologies and for comparing quantitatively the performance effects of motion sickness and radiation sickness. Furthermore, the method provides a framework for future improvements as symptomatology descriptions evolve and additional human performance data is acquired.

The second goal of this report was to determine the extent to which existing motion sickness data validate the estimates of performance degradation on Army combat crew tasks. The link between the symptomatologies established as the first goal above allows the following conclusions regarding those radiation sickness symptom complexes that can be mapped to the motion sickness symptom severity scale.

1. Rank ordering of symptom complexes according to the magnitude of performance decrement shows that relative performance decrements as judged by Army operational personnel are corroborated by performance data taken during motion sickness.

2. For performance levels from 1.0 to around 0.5, the range where symptoms are comparable, estimates by Army operational personnel of performance decrements from radiation sickness are quite similar in magnitude to the measured performance decrements of Coast Guardsmen during motion sickness.

3. Chi-squared tests showed that the estimates of performance degradation on the Army tasks, all of which had usual completion

times of a few to 60 seconds, were significantly better correlated with measured degradations on Coast Guard tasks also having completion times under a minute or so than with tasks which required over nine minutes of sustained performance.

Given that the Army and Coast Guard tasks being compared have elements in common but are not identical, the agreement between estimated and measured performance decrements is quite satisfactory. Being based on human performance data, these comparisons provide the strongest support to date for the validity of the estimates made by the Intermediate Dose Program on the performance degradation to be expected from acute radiation sickness.

SECTION 5

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APPENDIX A

KAST PERFORMANCE TASK BATTERY DESCRIPTION

The U.S. Coast Guard and Navy [see Wiker et al., 1980] used a performance task battery designed to assess the effects of both ship motion and motion sickness upon short-term memory, pattern recogni-tion, signal detection, information processing, and mathematical reasoning during the Kaimalino Sea Trials (KAST). These dimensions of human performance are used by the majority of artillery, tank, FDC, and TOW crew tasks addressed in the ORG questionnaire. The following paragraphs briefly describe each task and the KAST performance results.

KAST TASKS

Three main criteria determined selection of the tasks of the KAST battery: statistical reliability, historical use in motion sickness or related studies, and relevance to shipboard performance. The tasks ranged from simple to complex, from abstract to operational, and from self-paced to machine-paced. The following four tasks, navigation plotting, critical tracking, complex counting, and code substitution, all chosen from the KAST battery, are generally compatible with the measure of performance used in the Intermediate Dose Program.

Navigation Plotting (NP) Task

The primary requirement of any vessel is to navigate safely, accurately, and efficiently from one position to another. This act requires accurate and timely determination of vessel position and relative position and movement of other vessels or objects. To accomplish this goal requires the operation of electronic and mechanical navigation equipment, manipulation of plotting equipment, such as triangles and dividers, and utilization of nomograms in the attainment of geometric and trigonometric solutions. The Navigation Plotting task was developed to test these capabilities [Wiker and Pepper, 1978] and has proven to be a statistically reliable task if the total number of problems attempted is used as the measure of performance [Wiker, Kennedy, and Pepper, 1983].

The subject-paced task requires subjects to plot the relative movement of a target vessel using a pair of triangles, a compass, and the standard maneuvering board. In addition to plotting the relative movement, subjects must use arithmetic and geometric reasoning, as well as nomogram interpretation, to compute the relative course, speed, and closest point of approach of successive target vessel movements. The task can be mastered with practice, yet it is sufficiently complex to be considered demanding during the 9-minute trial.

Navigation Plotting combines a variety of perceptual, cognitive, and motor components of human performance which are most comparable to the tasks performed by the FDC Horizontal Control Officer (e.g., plot target location on chart, read range and deflection by protractor) and FDC Computer (e.g., calculate fuze setting, deflection, and quadrant elevation).

Critical Tracking (CT) Task

Many have found it useful to consider the human operator as a biological servomechanism that receives input from the sensory system, integrates the sensory information within the central nervous system, and produces an output in the form of a motor response [Jex and Allen, 1974]. Reevaluations of the output accuracy by the operator are made in a consecutive manner. However, due to the delay in time between the input and output processes, this servomechanism (the operator) is considered to be intermittent or discrete in nature. Tracking performance, or time on target, is, therefore, dependent upon the dynamics of the target, the functional integrity of the operator's sensory systems, central processing capability, and neuromuscular capacities. Investigators frequently employ tracking performance as a measure of the human operator's transfer function, or effective time delay between the incoming stimulus and outgoing response [Rose, 1974].

Many forms of tracking tasks can be used to measure effective time delays associated with exposure to stressful environments or situations (e.g., pursuit, compensatory, subcritical, and critical). The critical tracking task possesses several advantages over the other forms for several reasons. First, the task requires the subject to compensate for, or null out, an unseen evasive target whose dynamics are rapidly

and systematically increased until tracking capabilities are exceeded in a short period of time. This method allows several trials within a few minutes and reduces the probability of induced local muscle fatigue. Second, presentation of only the tracking error reduces the ability of the subject to anticipate target movement during the tracking task. This procedure makes the task more difficult and serves to improve task definition as defined by Jones [1979]. Finally, the tracking instability or bandwidth limit determination provides direct information concerning changes in the operator's transfer function and limits to dynamic control operation.

Many of the tasks examined in the ORG questionnaire involved manual control operations: particularly tasks performed by the Gunner and Assistant Gunner of the artillery crew (e.g., Gunner and Assistant Gunner set deflection and quadrant elevation, traverse tube, and level bubble), tank crew (e.g., Tank Commander ranges target; Gunner aims, fires, and applies fire adjustments), and the Gunner of the TOW crew (e.g., Gunner sets superevelation, adjusts magnification, acquires target and tracks target for last six seconds).

Complex Counting (CC) Task

Many of the tasks addressed in the ORG questionnaire require periods of sustained attention and use of short-term memory. Observations of the varying abilities of nephrology laboratory technicians in monitoring the number of drips produced from various numbers of kidneys led to the original conception of the Complex Counting task. Researchers later adpated this complex, or multiple, mental counting task to a three-light flashing display for investigations of sustained attention in high-noise environments. Kennedy [1971] compared visual and auditory forms of the test and found the auditory form to be the most difficult for subjects. He subsequently used the auditory form in an evaluation of the ride quality of three different types of aircraft penetrating hurricanes [Kennedy, Moroney, Bale, Gregorie, and Smith, 1972]. The test requires subjects to mentally count and keep track of the appearance of high, medium, and low frequency auditory tones. After the fourth occurrence of a particular tone is heard, the subject indicates the occurrence by pressing any appropriate button, "zeros" the mental counter for that

particular tone, and continues the process for 10 minutes. Percentage of tone "quartets" correctly counted for each tone serves as the scoring metric. The task is demanding even under ideal conditions that rarely produce error free performance when two or more tones (channels) are monitored.

Performance of the Complex Counting task is sensitive to changes in short-term memory capability, a factor used by several of the tasks examined by ORG. However, no task within the questionnaire required a long period of sustained attention or vigilance which is a chief characteristic of the Complex Counting task.

Code Substitution (CS) Task

Code Substitution is a paper and pencil test developed in the early 1900s to help select office and clerical workers in industry. The test is widely use, with some version employed in nearly every aptitude or intelligence test.

The form employed in the USGG study was an adaptation of the Otis [1939] digit ot letter substitution task. Wechsler [1939] employed the task in WISC because he felt that it tapped elements of perceptual speed and accuracy, an important dimension discovered in his earlier factor analytic study of human abilities. Because the task requires subjects to recode an alpha array using numeric recording matrix, the task corresponds to operational tasks, which require symbology transition.

Few if any tasks contained within the ORG questionnaire relate to performance associated with the Code Substitution Task.

EMPIRICAL PERFORMANCE RESULTS FROM THE KAST TRIALS

Table 7 lists the regression line equations for performance vs. MSSS score from the KAST trials. Figures 18 through 21 provide plots of the same information.

Table 7. Regression line equations relating task performance measures to MSSS score.

Navigation Plotting Problems Attempted
$38.53 - 3.93 \times MSSS$
Critical Tracking Oscillation Bandwidth Limit
$5.07 - 0.203 \times MSSS$
Complex Counting Percent Correct
$142.6 - 42.13 \times MSSS + 3.66 \times (MSSS)^2$
Code Substitution Attempts
$100.29 - 5.84 \times MSSS$

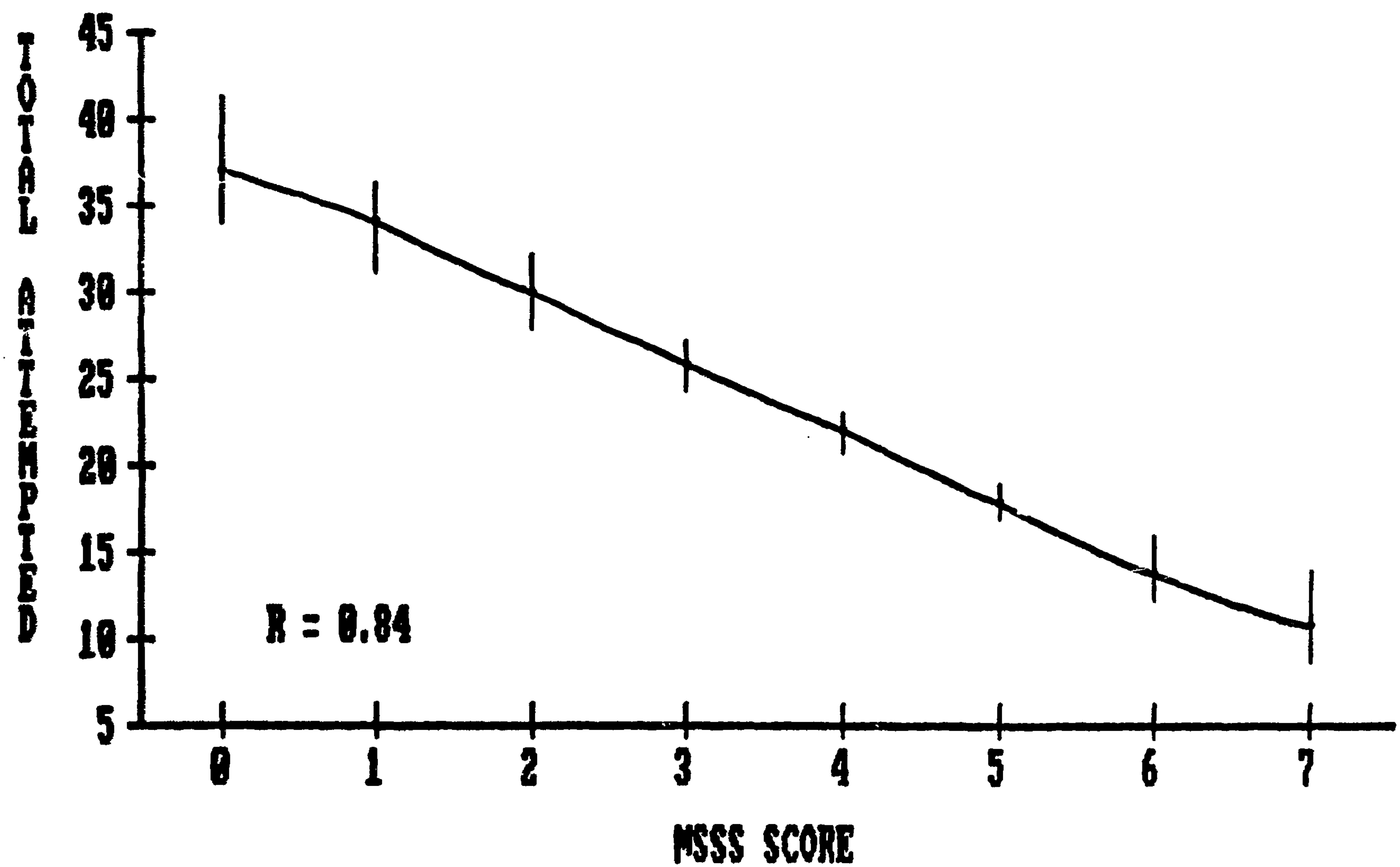

Figure 18. Navigation plotting vs. motion sickness severity.

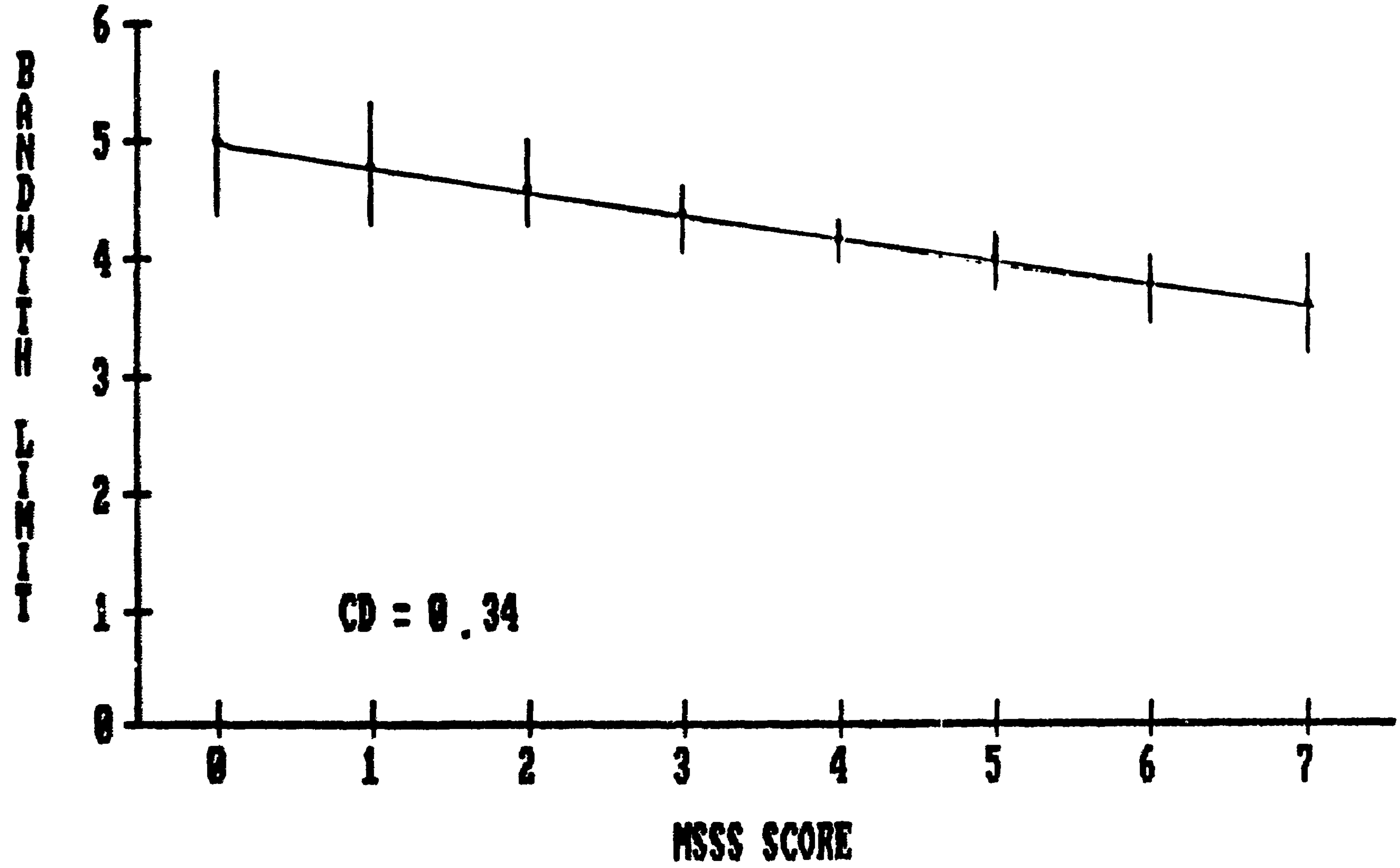

Figure 19. Critical tracking vs. motion sickness severity.

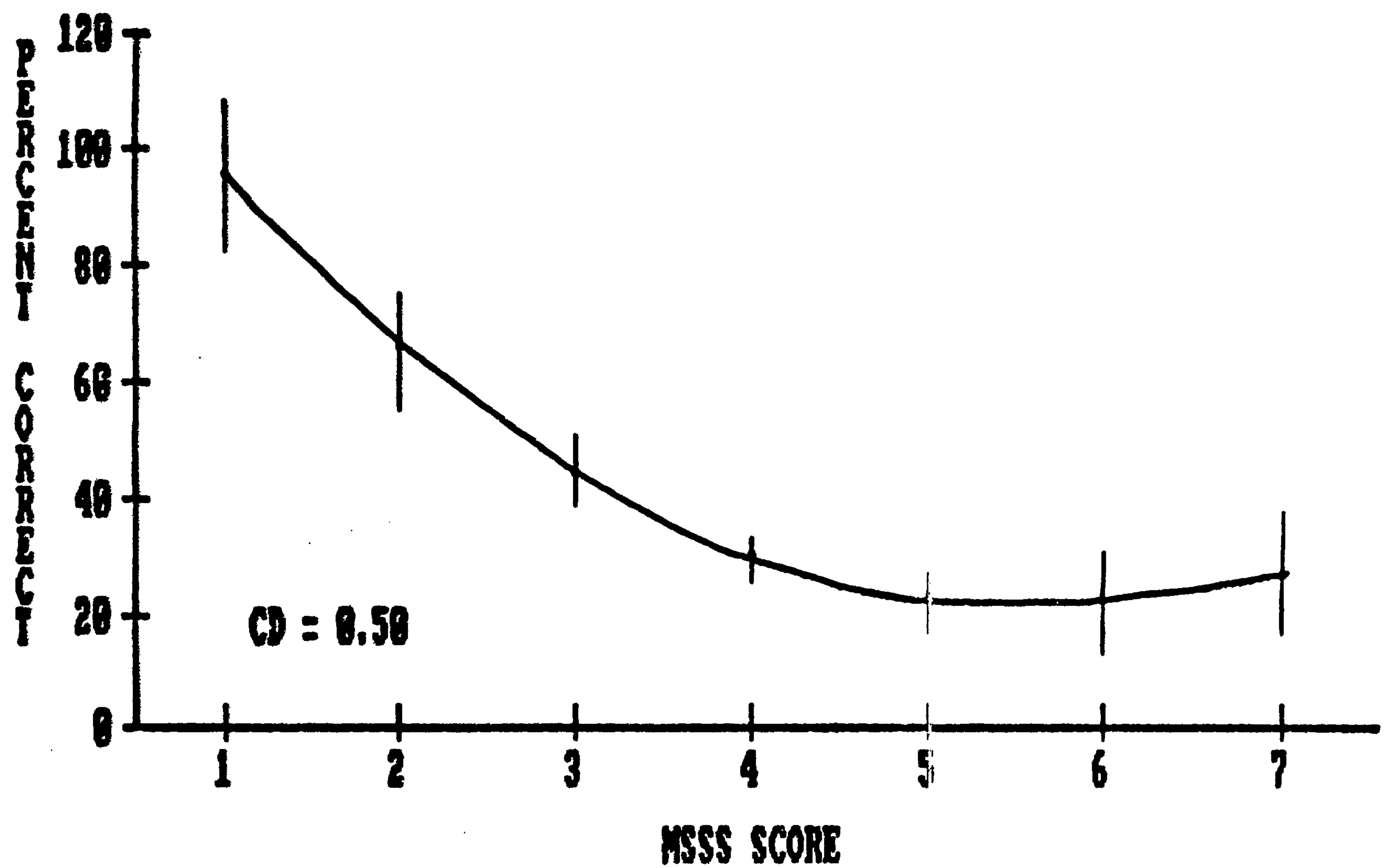

Figure 20. Complex counting vs. motion sickness severity.

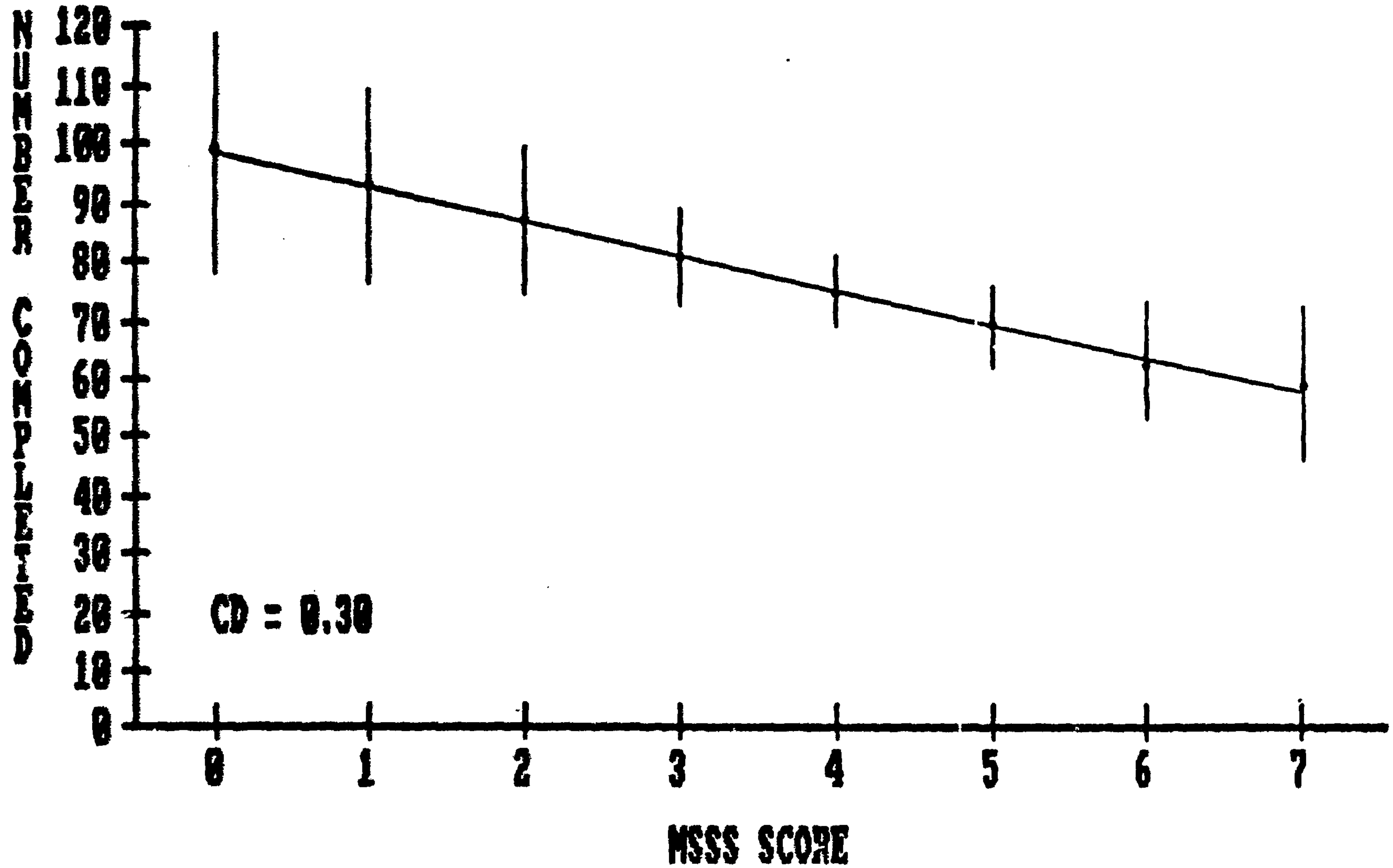

Figure 21. Code substitution vs. motion sickness severity.

APPENDIX B

REGRESSION ANALYSES OF IDP PERFORMANCE ESTIMATES VS. MSSS SCORE

This appendix presents the results of the regression analysis of the Army crewmember performance estimates vs. MSSS score. For each crew position (as ordered in Figures 2-16 of Section 3), the slope of the regression line and its standard deviation SIGMA(B) are listed. The associated data for each position are as follows:

x = MSSS score.

MU = Average performance for all RSS complexes at each MSSS score.

SIGMA = Standard deviation of MU.

SIGMA(E) = Standard deviation obtained by combining the five values of SIGMA.

The 2-σ curves plotted in Figures 2-16 are given by:

$$y = 1 + (\text{SLOPE} \times x) \pm 2\{[\text{SIGMA(B)} \times x]^2 + [\text{SIGMA(E)}]^2\}^{1/2}$$

POSITION # 1: SLOPE = -0.0770 SIGMA(B) = 0.0105
SIGMA(E) = 0.0613

X	MU	SIGMA
1	0.8119	0.2278
3	0.6242	0.1926
4	0.5340	0.1776
6	0.5594	0.1228
7	0.4913	0.0907

POSITION # 2: SLOPE = -0.0505 SIGMA(B) = 0.0104
SIGMA(E) = 0.0590

X	MU	SIGMA
1	0.8409	0.1852
3	0.7507	0.1910
4	0.7097	0.1535
6	0.7370	0.1150
7	0.6565	0.0942

POSITION # 3: SLOPE = -0.0563 SIGMA(B) = 0.0098
SIGMA(E) = 0.0565

X	MU	SIGMA
1	0.8073	0.1929
3	0.7220	0.1777
4	0.6511	0.1534
6	0.6970	0.1160
7	0.6260	0.0851

POSITION # 4: SLOPE = -0.0871 SIGMA(B) = 0.0110
SIGMA(E) = 0.0628

X	MU	SIGMA
1	0.6931	0.2266
3	0.5451	0.1959
4	0.4522	0.1623
6	0.5172	0.1179
7	0.4375	0.1009

POSITION # 5: SLOPE = -0.0485 SIGMA(B) = 0.0099
SIGMA(E) = 0.0517

X	MU	SIGMA
1	0.9352	0.1056
3	0.7229	0.1768
4	0.6882	0.1540
6	0.6975	0.1099
7	0.7045	0.0885

POSITION # 6: SLOPE = -0.0616 SIGMA(B) = 0.0097
SIGMA(E) = 0.0531

X	MU	SIGMA
1	0.8412	0.1391
3	0.6790	0.1635
4	0.6272	0.1401
6	0.6332	0.1081
7	0.6187	0.0879

POSITION # 7: SLOPE = -0.0457 SIGMA(B) = 0.0089
SIGMA(E) = 0.0476

X	MU	SIGMA
1	0.8764	0.1178
3	0.7582	0.1420
4	0.7312	0.1213
6	0.7338	0.0959
7	0.7191	0.0837

POSITION # 8: SLOPE = -0.0571 SIGMA(B) = 0.0098
SIGMA(E) = 0.0532

X	MU	SIGMA
1	0.8957	0.1319
3	0.8299	0.1459
4	0.6811	0.1558
6	0.6760	0.1155
7	0.6098	0.0868

POSITION # 9: SLOPE = -0.0411 SIGMA(B) = 0.0086
SIGMA(E) = 0.0437

X	MU	SIGMA
1	0.9355	0.0904
3	0.8782	0.1187
4	0.7875	0.1214
6	0.7690	0.1002
7	0.7174	0.0783

POSITION #10: SLOPE = -0.0627 SIGMA(B) = 0.0087
SIGMA(E) = 0.0487

X	MU	SIGMA
1	0.8384	0.1361
3	0.7535	0.1482
4	0.6067	0.1304
6	0.6351	0.1041
7	0.5948	0.0764

POSITION #11: SLOPE = -0.0453 SIGMA(B) = 0.0099
SIGMA(E) = 0.0517

X	MU	SIGMA
1	0.9057	0.1179
3	0.8156	0.1377
4	0.7163	0.1459
6	0.7590	0.1108
7	0.7013	0.0908

POSITION #12: SLOPE = -0.0579 SIGMA(B) = 0.0099
SIGMA(E) = 0.0482

X	MU	SIGMA
1	0.9075	0.0960
3	0.8282	0.1338
4	0.6291	0.1209
6	0.6424	0.1065
7	0.6551	0.0953

POSITION #13: SLOPE = -0.0714 SIGMA(B) = 0.0106
SIGMA(E) = 0.0531

X	MU	SIGMA
1	0.8736	0.1133
3	0.7783	0.1458
4	0.5248	0.1309
6	0.5674	0.1175
7	0.5748	0.1006

POSITION #14: SLOPE = -0.0266 SIGMA(B) = 0.0075
SIGMA(E) = 0.0333

X	MU	SIGMA
1	0.9617	0.0523
3	0.9018	0.0983
4	0.7573	0.1142
6	0.8559	0.0771
7	0.8414	0.0733

POSITION #15: SLOPE = -0.0576 SIGMA(B) = 0.0095
SIGMA(E) = 0.0428

X	MU	SIGMA
1	0.8932	0.0723
3	0.8148	0.1128
4	0.5648	0.1236
6	0.6795	0.1036
7	0.6590	0.0920

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